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THE ASTROPHYSICAL JOURNAL

An International Review of Spectroscopy and Astronomical Physics

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CONTENTS

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CONTENTS

NUMBER I

NUMBER II

NUMBER III

NUMBER IV

NUMBER V

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HERMANN CARL VOGEL

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AND ASTRONOMICAL PHYSICS

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HERMANN CARL VOGEL

By EDWIN B. FROST

It seems more fitting at this time to record the eminent services to science and the principal features of the life of this distinguished astrophysicist, rather than to seek appropriate words in which to deplore his loss, keenly as we feel it.

His place will be filled—no one man is any longer indispensable in the affairs of any properly regulated institution—and the splendid research observatory which he did so much to establish will continue its work, doubtless with little departure from the course which he had carefully laid out for it. But his pioneer researches, and his administrative achievements, opening an opportunity for many other significant investigations by his assistants and successors, have a permanent place in science. Their importance will later be even better appreciated than now, in the improved perspective which time alone can furnish.

Hermann Carl Vogel was born at Leipsic on April 3, 1842. As one of the youngest sons in a large family, in which high intellectual ideals prevailed, rather than considerations of material prosperity, his destiny was to be largely in his own hands. His father, Carl Cristoph Vogel, was a well-known educator, with practical tendencies, and superintendent of the schools of Leipsic. He was the author of several books on educational subjects and was the founder of the *Realschulen* of Leipsic, which afforded opportunity for a better preparation in prac-

tical and scientific lines for the subsequent university course than did the *Gymnasia*.

The intellectual inheritance and early training of this family is further evidenced by the careers of others of its members. An older brother of Hermann, Eduard, after completing a brilliant course at the university, was called to London to take part in the work of Mr. Bishop's private observatory, then in charge of Dr. Hind. Diverted from astronomy by his interest in exploration and the natural sciences, he entered in 1850 upon extensive and ultimately fatal travels in Africa, under the auspices of the Royal Geographical Society. A sister was well known in recent German literature under the pseudonym of Elise Polko, writing principally on topics connected with music.

The natural tendencies of Hermann Vogel were toward practical things: his early intention was to become a locomotive builder. This interest and ability in mechanical matters was of much advantage in his subsequent career, greatly assisting him in designing new instruments and apparatus. While at the Polytechnic in Dresden both of his parents died, and his lack of both health and means compelled him to forego his ambitions for a profession in technology. At this juncture relief came in the person of a Russian prince desiring instruction in photography, which Vogel later assisted in making such a powerful auxiliary of the new astronomy. With the assistance of his patron he was able to get a fresh start, and he returned to Leipsic. Here, Carl Bruhns, himself a self-made man, recognizing young Vogel's ability, gave him a position in the newly established observatory at the princely salary of $150 per year. The columns of the *Astronomische Nachrichten* from 1866 onward attest to the activity of the young assistant in his new position, his observations being chiefly on asteroids, comets, and nebulae.

At this period Zöllner was by his masterly researches opening the way for astrophysics, and his influence is doubtless in a measure responsible for Vogel's subsequent interest in this branch. Vogel was meanwhile pursuing his studies in the university, although his lack of funds did not allow him to hear many of the courses of lectures. In 1868 he took his doctor's degree at Jena with a thesis on the micrometrical determination of the positions of nebulae and star clusters, with a historical sketch of the observations of nebulae.

In 1870 he was appointed director of the newly established and finely equipped private observatory of Chamberlain von Bülow at Bothkamp in Holstein, not far from Kiel. Here in the next four years he planned and executed many important researches in astrophysics, which are recorded in the first two volumes of publications of that observatory. A large part of the programme was given to spectroscopic observations of sun, stars, nebulae, planets, comets, aurora, and lightning, including line-of-sight measurements on sun and stars. Provision was also made for solar photography, the dry-plate process of Fothergill, as modified by Gordon, being successfully employed (1871).

The work at Bothkamp was done with the assistance of Dr. O. Lohse, who was subsequently one of the first observers appointed at the Potsdam Observatory.

It is interesting to note that the admirable style of publication later characteristic of the Potsdam *Publicationen* was introduced by Vogel in the volumes recording the observations made at Bothkamp.

The work so effectively commenced at the private observatory was not long to be continued, for the call soon came to the young man to enter the service of the Prussian state, and assist in developing plans for an astrophysical observatory to be established in the vicinity of Berlin. The brilliant researches of Kirchhoff had aroused the desire for such an institution, which at first was planned to be rather a *Sonnenwarte* than a *Sternwarte.* The interest of the crown prince, later Kaiser Friedrich, materially assisted toward the realization of the hopes of the scientific men principally active in the new enterprise. The minister of education in 1873 appointed a special committee, with Professor E. du Bois-Reymond as chairman, and the work of preparing plans for the institution was undertaken by a subcommittee consisting of Professors Auwers, Förster, and Kirchhoff. In 1874 appointments were made of two observers, Professors Vogel and Spörer, the latter having become well known for his faithful observations of the sun while a teacher in the *Gymnasium* at Anklam; and to them was assigned the duty of planning the initial instrumental equipment of the institution, the site for which had now been definitely located in the "Telegraphenberg" at Potsdam. In connection with these

duties Vogel made a visit to England, Scotland, and Ireland, ordering some of the instruments. Otherwise he traveled but little.

The first idea of having the new institute associated with the Observatory of Berlin was given up, and no provision was made for instruction. The observatory was not completed until 1879, but during these five years largely devoted to planning and executive duties, Vogel's observational activity was not suspended, and a number of his earlier pieces of work were published. Until 1882 the scientific and business administration of the institution was provisionally in the hands of a directorate consisting of the three gentlemen previously serving as a subcommittee. Vogel was then appointed director, a position he was to fill with eminent success for the next quarter of a century.

The equipment of the new institute was admirably adapted to its purposes, and fairly liberal appropriations were made for new apparatus; the principal telescopes (refractors of 13-, 8-, and 5-inches aperture) were, however, comparatively small. Activity was principally directed to celestial spectroscopy, celestial photometry, observations of the solar surface, both visual and photographic, direct planetary observations, and laboratory investigations of a physical nature. The director was fortunate in his choice of assistants, as the budget gradually permitted an enlargement of the staff; results were promptly published, in separate parts, as they were ready, in a clear and sufficiently detailed manner, which might well serve as a model for other institutions; and the premier position of the observatory in astrophysics was very soon established.

During Professor Vogel's administration the principal new developments were (1) the application of photography in stellar spectroscopy, particularly for determinations of velocities in the line of sight; (2) the construction of a new style of instrument (32-cm refractor) for stellar photography, and co-operation in the planning and subsequent work on the astrographic chart; (3) the construction and equipment of a large (80 cm) refractor particularly adapted for astrophysical research.

The first of these new departments opened the way for the modern investigations of the radial velocities of stars; it caused the evolution of the spectroscope into the spectrograph, and led to new types of

construction of that effective instrument both at Potsdam and elsewhere; it carried much farther the pioneer work of Huggins on photographic spectra of stars. It also led (1889) to the spectrographic demonstration of the correctness of the eclipse theory of the light-variation of *Algol*, which Vogel had unsuccessfully attempted with a visual spectroscope in 1875; and to the discovery of the existence of spectroscopic binary systems in which one component star was relatively dark (*Spica*, 1889). Vogel's name will perhaps be longest remembered for this discovery of spectroscopic binaries; and he will share in its credit with Professor E. C. Pickering, who was simultaneously interpreting in a similar manner the varying duplicity of lines in the objective-prism spectra of *Mizar* and *β Aurigae*.

By his use of metallic terminals (iron) as a source of the comparison spectrum, in addition to, or substitution for, the hydrogen tube generally employed, Vogel also opened the way for what is now the universal practice, although he seems not to have fully appreciated its advantage, and only employed the method in exceptional cases.

In 1892 he was able to publish (Bd. VII, Theil I) a catalogue of the radial velocities of 52 stars determined with a precision very superior to that of the visual measures then extant, which were hardly competent to give even the direction of motion of the stars—whether approach or recession; and in view of the extreme difficulty of such measures visually, this may be said without any discredit to the visual observers. In these spectrographic investigations, as in many others, Professor Vogel had the efficient collaboration of Dr. Scheiner.

With this list of stars the limit of the 12-inch (30 cm) Schröder refractor was practically reached for spectrographic observations, and for this work the director's desire grew keener for a larger telescope, comparable with those in use in foreign observatories. But the government's financial condition did not then permit the desired enlargement of the telescopic equipment.

Meanwhile the observatory undertook an active part in the preparations for the astrographic catalogue (but abstained from co-operating on the astrographic chart), and the photographic refractor of 32.5-cm (12.8 in.) aperture and 343-cm (145.7 in.) focal length was designed on a new principle and constructed by Repsold (optical parts by Steinheil). The pier was made of two riveted castings set at such

an angle that the upper casting pointed toward the pole,[1] permitting an unhindered motion of the instrument in right ascension (a point of great importance in long exposures) and combining the advantages of the so-called "English" and "German" types of mounting. The guiding telescope, rigidly attached within the same tube, is of aperture 23.5 cm and of the same focal length. This effective telescope was Vogel's favorite instrument in recent years and he designed in succession a number of spectrographs for it, after a provisional spectrograph had yielded useful results on *Nova Aurigae* in 1892.

In conjunction with Professor Wilsing he published in 1898 a valuable work of reconnaissance entitled *Untersuchungen über die Spectra von 528 Sternen* (from spectrograms taken with this telescope), dealing principally with stars of the first type and referring especially to the presence in them of helium. Professor Vogel's last published paper (constituting Part 1 of the fifteenth volume of the Potsdam Publications), issued shortly before his death, gives a detailed description of "Die zwei Doppelrefraktoren des Observatoriums," referring to this telescope and the great 80-cm refractor to which allusion will next be made.

It is doubtful if any large refractor has ever been constructed with a more thorough advance study of its adaptation to the purposes for which it was to be used than this great photographic telescope of 31.5-inches aperture. Extensive measurements were made at the observatory of the absorption of various kinds of glass for the different rays, and the size of the objective was determined in accordance with the data gained.[2] During the years of waiting for the necessary grant from the government, the details of the mechanical construction had been minutely worked out, so that contracts could be let quite promptly after imperial influence had led to the authorization of the instrument in 1895. Some features were novel, particularly in regard to the observing platform. The large object glass, when delivered, was subjected to more extensive and thorough tests, chiefly by Pro-

[1] It was long supposed by all concerned that this design was unique, but it subsequently appeared that a similar type of construction had been used at the Orwell Park Observatory, Ipswich, England, in 1874.

[2] H. C. Vogel, "The Absorption of Light as a Determining Factor in the Selection of the Size of the Objective for the Great Refractor of the Potsdam Observatory," *Astrophysical Journal*, 5, 75–91, 1897.

fessor Hartmann, than has probably ever been the case previously. In his last paper Vogel gives an interesting account of these investigations, which must have given him much concern, and he candidly prints both the more favorable and the less favorable opinions of those charged with making trials of the performance of the lens. This somewhat extended reference to the construction of these telescopes is made here, because they absorbed no small part of the director's energies in recent years. He writes with a natural satisfaction that during his administration the instrumental equipment could thus be brought to a certain state of completeness, particularly as provision had also been made for securing reflecting telescopes of short focus, the advantages of which he fully appreciated.[1]

In his astrophysical researches and publications Professor Vogel's attitude was rationally conservative, but his mind was fully open to new developments. His point of view may be seen from *Newcomb-Engelmanns Populäre Astronomie*, two editions of which he edited. The last edition (1905), practically a new book, is now probably the best work on astronomy for the general reader. Of his contemporaries in pioneer astrophysical research, he seemed most in sympathy with Huggins, whose views were much like his own.

Vogel's published papers are very numerous. Aside from his many observations and orbital computations on asteroids and comets, he observed the satellites of *Jupiter* and *Uranus*, and triangulated the star cluster χ *Persei* while at Leipsic. He also made an extended study of the absorption in the solar atmosphere of the chemical rays, which was published in the *Berichte* of the Royal Saxon Academy for July 1, 1872. This research was extended to the yellow rays at Bothkamp, and was later (1876) greatly broadened so as to include many spectral regions, the observations being made with Vogel's modification of the Glan spectral photometer attached to the 9-inch refractor of the Berlin Observatory. It was published under the title "Spectralphotometrische Untersuchungen insbesondere zur Bestimmung der Absorption der die Sonne umgebenden Gashulle," in the *Monatsbericht* of the Berlin Academy for March, 1877 (41 pages). A brief set of spectral photometric observations of stars was also made at

[1] H. C. Vogel, "On Reflecting Telescopes of Relatively Short Focus," *Astrophysical Journal*, 23, 370–389, 1906.

Berlin, in conjunction with Dr. G. Müller, and later published by the same society.

An early investigation of much importance was ***Untersuchungen über die Spectra der Planeten*** (8vo, pp. 64, Leipsic, 1874), which was successfully submitted for a prize competition of the Copenhagen Academy of Sciences. These difficult visual observations were made at Bothkamp and include all the major planets, two asteroids, and the satellites of *Jupiter*. Twenty-one years later Vogel contributed to the Berlin Academy a paper upon the same subject: "Neuere Untersuchungen über die Spectra der Planeten." He comments on the fact that the observations of planetary spectra elsewhere published in the lapse of two decades had hardly done more than confirm his original results. This later discussion of the subject was based upon spectrograms taken for the most part with low dispersion, but not including the more refrangible regions of the spectrum. In the case of *Mars*, Vogel also made visual observations which appeared to confirm the earlier detection of atmospheric bands.

At Bothkamp he observed the Doppler effect at the opposite limbs of the sun, due to its rotation, and he made some observations of sun-spot spectra and prominences; but in solar spectroscopy his principal piece of work was his ***Untersuchungen über das Sonnenspectrum*** (Part III of the first volume of the Potsdam Publications), in which, in conjunction with Professor Müller, he measured directly and on photographs the positions of some 2,600 lines between E and H, referred to Ångström's scale, and charted their positions in an atlas. The inaccuracy of Ångström's system being increasingly felt, new absolute determinations of the wave-lengths of 300 lines in the solar spectrum were later made by Müller and Kempf, and the 2,600 lines of Vogel's list were re-reduced to this system. These, with others measured by Müller and Kempf, making a total of 4,020 lines, constituted the Potsdam system of wave-lengths. But Rowland's photographic map, made with the concave grating, and his more extensive tables of wave-lengths, soon appeared and naturally superseded all others.

Vogel's field for personal research in the last twenty years was almost entirely in stellar spectroscopy. He had devoted much time to visual spectra at Bothkamp, and upon those observations he based his widely used classification of stellar spectra, first stated in ***Astrono-***

mische Nachrichten, (**84**, 113, 1874). While adhering to Secchi's classification in a general way, Vogel enunciates distinctly that the guiding principle should be that of stellar development. He regards Secchi's third and fourth types as co-ordinate, distinguishing them as subdivisions of his third type. Vogel's system also makes an important addition, in differentiating three subdivisions of the first type, thus providing for stars of the *Orion* type and those having bright lines like γ *Cassiopeiae*. He also added a second subdivision to the second or solar type, II*b*, to include stars of the Wolf-Rayet type, having bright lines.

In a paper presented to the Berlin Academy in 1895, "Ueber das Vorkommen der Linien des Cleveitgasspectrums in den Sternspectren und über die Classification der Sterne vom ersten Spectraltypus," he avails himself of the data meanwhile gained by photography, and particularly after the discovery of helium, and the assignment to it of many significant lines previously unidentified, and he further differentiates the spectra of the first type. Subdivisions I*a*1 and I*a*2 and I*a*3 represent very marked differences in spectra. This restatement of his classification, particularly applying to the first type, is also given in the valuable paper on the spectra of 528 stars, already referred to (Bd. XII, Stück 1, *Publicationen*, Potsdam).

An earlier spectroscopic investigation, undertaken in conjunction with Dr. Müller, forms the third part of the third volume of the observatory's publications. It was the beginning of an attempt at a spectroscopic *Durchmusterung* of all the stars to magnitude 7.5 (inclusive) of the northern heavens. This paper (published in 1883) gives the results of a visual examination of over 4,000 such stars in the zone from $-1°$ to $+20°$ of declination. All honor to the skill and perseverance of the observers! Present-day workers who have dealt wholly with photographic spectra can scarcely appreciate the difficulties of such visual observations. This particular investigation was not extended to other zones, as the paramount advantages of photography for such surveys had meanwhile been demonstrated, principally at the Harvard Observatory by E. C. Pickering.

After his election to a seat in the Berlin Academy of Sciences in 1892, Vogel's papers chiefly appeared in the publications of that society, and were commonly translated for the *Astrophysical Journal*

from advance sheets at his request. These papers show the same careful study, and cautious, undogmatic expression, in regard to the qualitative part of an investigation as to its quantitative features, and they may well serve as models for younger men. Among these articles the following may be mentioned particularly:

"Ueber den neuen Stern im Fuhrmann," 1893, an especially thorough study of *Nova Aurigae* (60 pages).

"Ueber das Spectrum vom *β Lyrae*," 1894.

"Ueber das Spectrum von *Mira Ceti*," 1896.

"Ueber das Spectrum von *α Aquilae* und über die Bewegung des Sterns im Visionsradius," 1898.

"Ueber die in letzten Decennium in der Bestimmung der Sternbewegungen in der Gesichtslinie erreichten Fortschritte," 1900.

"Ueber das Spectrum der *Nova Persei*," 1901.

"Der spectroskopische Doppelstern *Mizar*," 1901.

"Ueber die Bewegung von *α Persei* in der Gesichtslinie," 1901.

"Ueber die Bewegung des Orionnebels im Visionsradius," 1902.

"Der spectroskopische Doppelstern *ο Persei*," 1902.

"Untersuchungen über das spectroskopische Doppelsternsystem *β Aurigae*," 1904.

Appreciative references to Vogel's many inventions and devices in connection with spectroscopic apparatus will be found throughout Scheiner's *Spectralanalyse der Gestirne*.

Personally Professor Vogel was quiet and reserved; his health had been poor for a number of years, and it was only by the strictest care of himself that he was able to accomplish so much. He was a staunch friend, and always encouraged conscientious work of men younger than himself. Faithful to the memory of an early attachment he never married, but he took a warm interest in the *Familienglück* of his friends. He found great solace and relaxation in music, and both a large and small organ were at hand in his house. Sometimes, too, he went down to the famous old church in the crypt of which lies the body of Frederick the Great, and there played on the large organ with himself the only auditor. He had always been interested in entomology and had a fine collection, which he delighted in showing to interested friends. He frankly appreciated approbation, and was

the recipient of many honors, and of elections to membership in most of the leading learned societies of the world.

The condition of his health took a rather sudden change for the worse in the past summer, and on the evening of August 13, he passed away. Two days later he was borne for the last time to the great dome, where funeral services were appropriately held on August 17.

His achievements in research now become a part of scientific history; the memories of his personal qualities are a priceless possession of those privileged to be his friends.

CONTRIBUTION TO THE STUDY OF THE PHOTO-SPHERE

By S. CHEVALIER

Although originated by M. Janssen at Meudon thirty years ago, the study of the granules of the photosphere has, as far as I know, made but little progress. But many questions may be raised concerning these granules. Besides those of a theoretical nature, which are still remote from our knowledge, there are many which do not transcend the mere statement of existing reality, and nevertheless they cannot be settled without difficulties. The dimension and form of the granules, their formation and transformation, their movements on the surface of the sun are some problems to which a good deal of attention has been paid at Zô-sè during the last two years. Though our investigation of the question is still far from being complete, the results already obtained seem to be worthy of publication.

Visual observations seem utterly powerless to solve such problems; photography therefore must be resorted to, if we are not reduced to the spectroscope alone. But though it is generally admitted that photography is not unsuited for the study of the photosphere, it must be confessed that photographs which can be used for this purpose are quite difficult to get, and when obtained, their interpretation is a matter of no little difficulty. The photographs made at Meudon by M. Janssen, though remarkably fine and clear, were crossed by a series of figures either circular or polygonal. While in the intervals between these figures the granules were quite clear and well shaped, inside of the figures they were distorted and tempest-tossed, so as almost to disappear. This appearance was considered by the best observers as due to a solar phenomenon, and was called by M. Janssen "photospheric *réseau.*" Nevertheless, this net of figures has nothing to do with the photosphere. As far as I know this fact is now generally acknowledged. In the *Bulletin de la société astro-*

nomique de France for April 1906, M. Hansky, in a paper entitled: "Photographie de la granulation solaire," begins as follows:

> Les travaux de M. Janssen ont fait époque dans les études du soleil. Dans ce genre de recherches l'agitation de l'atmosphère trouble les images de telle façon que dans quelques endroits du disque solaire seulement, on obtient la photographie de la surface granulaire; le reste est flou et n'est que l'image des ondes de notre atmosphère qui passent au moment de la pose entre l'objectif et le soleil. Ainsi s'expliquent les différentes espèces du réseau photosphérique découvert par M. Janssen.
>
> Les conditions atmosphériques permettant d'obtenir la vraie forme de la granulation solaire sont si rares que, même dans la grande collection des photographies du soleil de l'observatoire de Meudon, on n'en trouve que très peu sans réseau photosphérique. Parmi les meilleures faites dans l'intervalle de quelques minutes on ne reconnaît plus les mêmes granules. Et même les photographies faites simultanément avec deux lunettes semblables n'ont donné aucune ressemblance dans les détails de la surface solaire.

This last fact is quite surprising, as the clear places of these photographs represent unquestionably the true granules of the photosphere; unless, indeed, they were so spoiled by the spurious *réseau*, that the places which were clear on one photograph happened to be troubled on the other.

As to the cause of these troubles, M. Hansky looks for it in the atmospheric waves between the object glass and the sun. This does not seem at all impossible, but as it is not altogether evident, there is room for some other assumption, and as the matter is worth discussing, the arguments in favor of a contrary opinion will not be out of place here. Since the phenomenon is not solar, we can assume: (1) that it is produced by waves of the air, there is no other cause to answer for it; (2) that these waves, whether inside or outside of the telescope, must be remote from the object glass and near the focal plane, if inside; or so distant, if outside, that their image may be formed near the focal plane. Now if we suppose that these areas of confused granules are images of outside waves, it seems quite evident that they will be printed on plates placed at the focus of the refractor, as well, and as often as in an enlarging camera. Indeed, every atmospheric wave at infinite distance for a refracting system equivalent to an object glass of 20 meters focal length, will certainly be so for a telescope of 7 meters. But according to our own experience,

this is not a fact. While this *réseau* is quite frequent when working with an enlarging camera, it is but slightly marked here and there on the plates placed at the focus of the refractor. Whenever the images of the sun are very fine, the granules of the photosphere are brought up on the latter plates, equally quiet and well shaped everywhere. Soon after, when working with an enlarging camera, we see the granules appear here and there quiet, here and there confused, here and there as if blown with a tremendous wind.

As this fact is general, I conclude: first, that the cause which brings up the areas of confused granules, so strongly and so generally marked on photographs obtained with an enlarging camera, is not outside, but lies somewhere inside of the telescope, and depends on some of the new conditions introduced by the camera; and secondly, that this fact entitles us to suppose that very probably the similar markings which appear on plates placed at the focus are due also to waves inside of the telescope.

Among the new conditions introduced, the most striking is certainly the addition of a new refracting system very near to the focus of the first object glass. It cannot fail to be intensely heated and consequently the air brought in contact with it must be set in motion. This lens, at least when it consists of a large concave lens placed inside of the focus of the telescope, is not contributing with every part of its surface to the formation of the image of every point of the sun. The rays of light, converging to form the image of a point, pass through only a portion of it. Small waves on its surface therefore may disturb several parts only of the image, and produce the so-called photospheric *réseau*. In case of a convex magnifying glass, the disturbances in the focal plane of the telescope would be photographed together with the image of the sun. As no other condition introduced by the enlarging camera seems so adequate to the production of this phenomenon, we may rationally suppose that it is due to this cause.

Guided by these considerations, I tried some experiments to see how far facts would support my view. I used an enlarging camera, first shutting out the rays of the sun some distance ahead of the magnifying lens and admitting them just at the time of releasing the shutter. I then allowed the rays to reach the lens for some time before releasing. If the *réseau* is produced by the lens the photographs

would be different in the two methods. Otherwise they would not. I found that there was always much to be gained by the first mode of operating, and the longer the exposure to the sun, even within five minutes, the worse were the photographs.

The magnifying system employed in these experiments is formed with two lenses. The first, which is carried inside of the focus of the telescope, is a convexo-concave lens of 30 mm aperture; the second, at an invariable distance from the first, is a biconvex lens of still less diameter and focal length. Besides photographing only a small portion at a time, the system is probably otherwise ill adapted for photography of the sun. The air inclosed in the brass tube between the two lenses must be intensely heated and set in motion. I hope soon to be able try another system and complete these experiments.

As to the traces of this *réseau* found on plates placed as the focus of the telescope, though I could not for the present assert anything, I incline to think that they are due also to air waves inside the telescope. We can well fancy such a combination of short atmospheric waves that would produce this effect. But whether this conception is consistent with the state of our atmosphere is not so evident. Although I do not intend to discuss all the conditions requisite for good photographs of the photosphere, I think advisable to discuss here two opinions which are generally held by astronomers.

The first is relative to the dimensions of the images necessary to bring up the details of the photosphere. M. Janssen in his note on the photospheric *réseau* (*Annuaire du bureau des longitudes*, 1878) wrote: "Les images dont le diamètre ne passe pas 10 à 12 cm ne peuvent montrer les détails de la structure photosphérique." This assertion, based on the experiments of the author, must be accepted as undoubtedly true under the conditions in which he was working; viz., with an object glass of a rather short focal length and a magnifying system. But it cannot be extended to the case of an object glass of a rather large aperture with a proper focal length. In fact, we get at Zô-sè the details of the photosphere on images of scarcely more than half the size specified, viz., 63 to 65 mm. This may be the smallest possible size, as most of the granules are not more than 0.03 mm in diameter on such photographs. But this shows that a simple object glass of long focal distance with a convenient aperture

is far better than any other system of refractors. The second question is relative to the time of exposure necessary to bring up the details of the photosphere. Mr. Maunder, at a meeting of the Royal Astronomical Society in speaking of the photography of the sun at Greenwich, said:

> The great difficulty in solar photography is getting the exposure sufficiently short, and in summer time the normal exposure given is equivalent to $\frac{1}{3000}$ part of a second. This in order to bring up spot detail. To bring up granulation detail, as in M. Janssen's photographs an exposure shorter still must be given.[1]

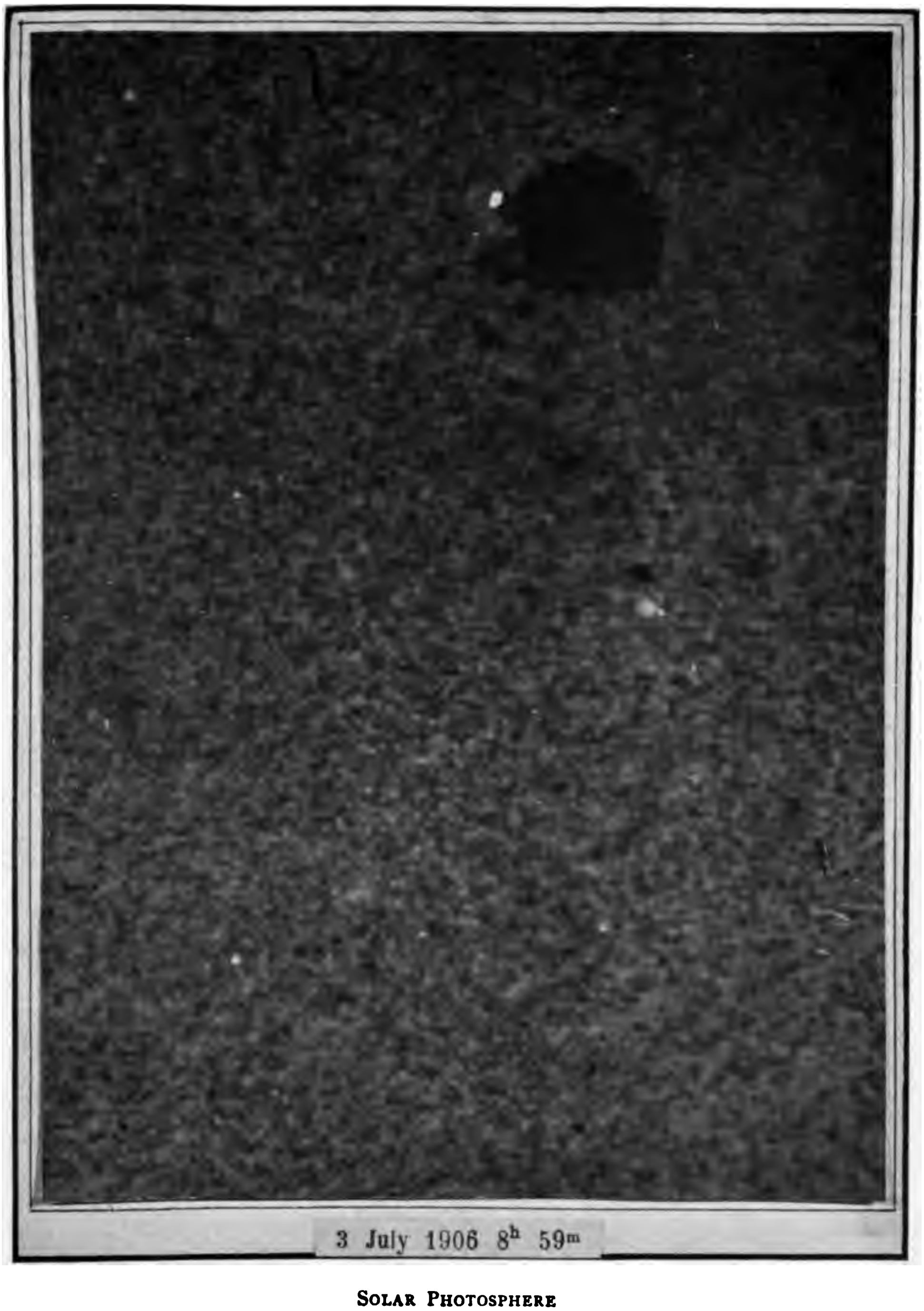
There are two points in the statement of Mr. Maunder which do not agree at all with our experience at Zô-sè: first, that to bring up photospheric detail it is necessary to give a shorter exposure than to bring up spot detail; second, that so short an exposure as $0^{s}.0003$ is necessary to bring up spot detail. If by spot detail he intended to include only the larger features of a sun-spot, as umbra, penumbra, and bright "bridges" over the umbra, we should agree with him that they are more easily brought up than the photospheric details. But if, as we think, the thin filaments of the penumbra, or faint details of the umbra were meant, then our experience is certainly to the contrary; it is much easier for us, with the same exposure, to bring up the photospheric details. With our object glass diaphragmed to 30 cm the exposure for a plate at the focus of the telescope is $0^{s}.001$, but is equivalent to $\frac{1}{3000}$[2] part of a second as at Greenwich. When working with a camera magnifying the image to eleven diameters we make the exposure equivalent to $0^{s}.001$. In case of fine and quiet images, a rare occurrence indeed, we do not find these exposures to be too long either for photospheric detail or for spot detail. In other cases, the shorter the exposure the less the photograph is troubled by the motion of the air in every kind of detail.

It would be interesting to know whence come these differences; but I can only surmise that the kind of plates used and the method of development adopted have much to do with them. We have tried plates of several makes and found that, for clearness of the image and plenty of minute details, there are enormous differences between

[1] *The Observatory*, 30, 76, 1907.

[2] The slit of our shutter is 1 mm broad, its speed is nearly 1 mm in $0^{s}.0003$; on account of its distance from the plate, the strip of plate exposed at one time is 3 mm broad.

PLATE II



SOLAR PHOTOSPHERE

plates even when nearly of the same sensitiveness. All the chloride or so-called lantern plates have been found by far inferior, for this work, to the slow bromide plates, such as the Lumière Red Label plates.

I come now to the results of our research on the granules of the photosphere. I will say a few words on their dimensions and forms, their duration, and their movements on the surface of the sun. As all these results depend on our photographs, I must first present to the reader the plates selected to illustrate this paper.

The first is an enlargement to eleven diameters of a photograph obtained on July 3, 1906, at $8^h\ 59^m$. It is specially intended to exhibit on a convenient scale a portion of the photosphere, large enough to show its general appearance. It is not the best specimen we could produce, but it has been purposely selected for the traces of photospheric *réseau* it bears. There are certainly disturbed places, but details are not all confused beyond recognition. The two following plates are intended, on the contrary, to make clear the minute details of the granules of the photosphere. The enlargement of the original plates has been carried to 33 diameters so that one millimeter on these photographs represents only $0\overset{''}{.}9$ on the disk of the sun. Each plate contains a set of two photographs taken within one minute of each other; and the portion of the disk found on the two photographs is exactly the same. The differences observed in the granules of the two images therefore must, if we were not mistaken, be accepted as representing changes which really took place on the surface of the sun. Defects of the film of the original plates have been purposely left uncorrected, but they are apparent, and with some caution the reader will distinguish them from the true features of the photosphere. When one takes several photographs of the sun within a short space of time, many differences are often noted mostly coming from difference in clearness in the photographs. But I think that in the present case the reader will distinguish what is due to a defect of the film or to differences in clearness from what is caused by real changes in the photosphere.

Form and dimension of the granules.—The diameter of the granules as measured on the present photographs varies nearly from $1''$ to $3''$. It would be quite useless to measure a great number of

them in order to get a mean diameter, inasmuch as their edges are by no means sharp and definite. We must rather inquire whether 1″ is really the lowest limit of the granules. In fact, on the original plates, 1″ represents 0.03 millimeter, which is very nearly the smallest detail obtainable by photography, especially with such a difficult object as the sun. On pictures of sun-spots taken with the help of an enlarging camera, the lowest limit is certainly below 1″. For instance, on the photograph of a sun-spot reproduced in the *Astrophysical Journal*, May 1907, many granules were found, particularly near the spot, the diameter of which does not exceed 0.″3; and in many places it looks as if the larger granules were formed by the union of smaller ones. I found indication of the same formation on several other photographs taken with the same instrument. And of course it is very probably so. There is, however, no substantial difference between the photosphere and its granules as they appear on these photographs, and those we now present, obtained by enlargement of plates taken at the focus of the telescope. Everyone can see for himself that the granules are of a more or less circular form, or rather, are ellipses of small eccentricity. This common shape is often altered; but very generally it looks as if it was so by outward circumstances, as pressure from other granules, union with some other one, etc.

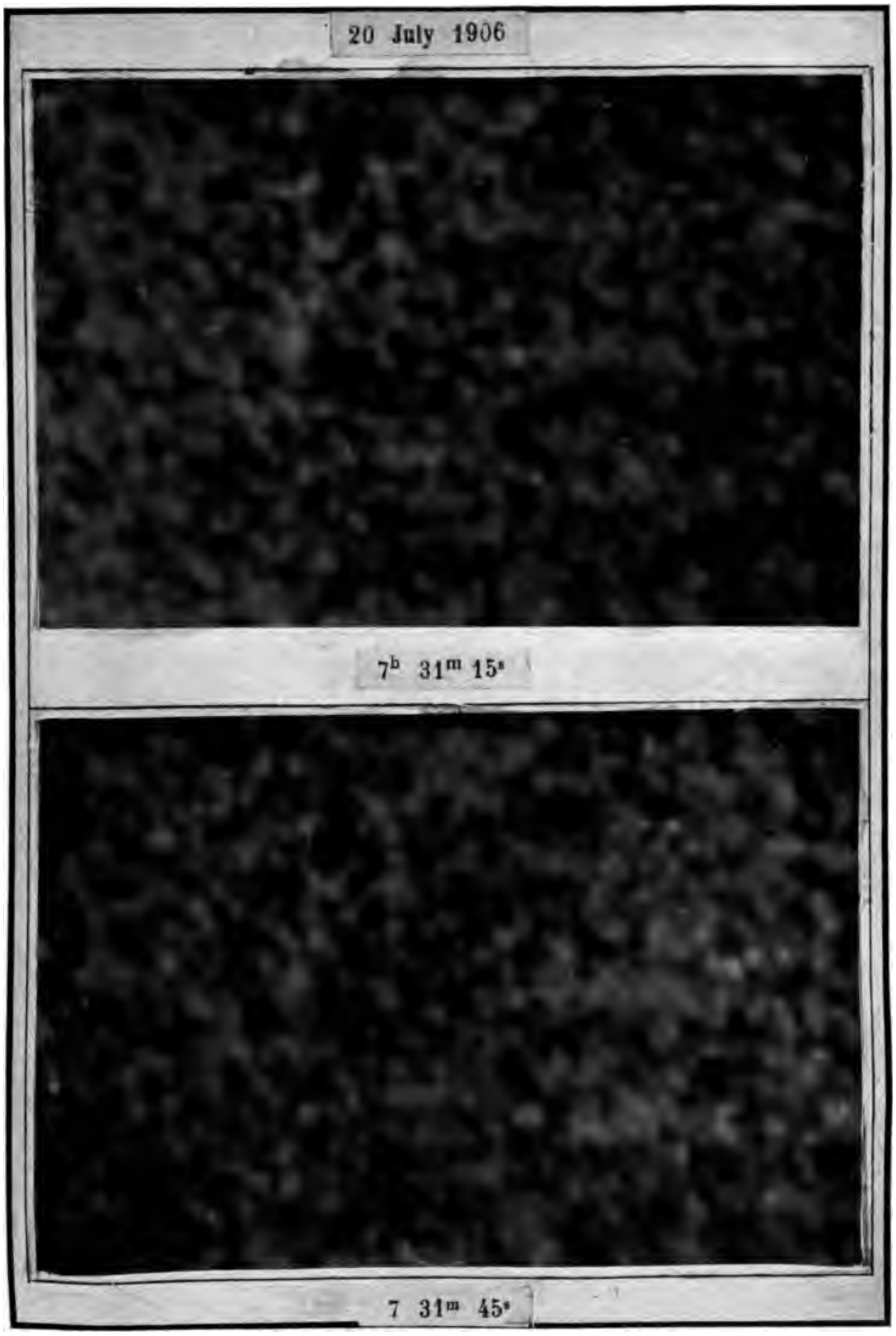
It would be a mistake to look at those granules as at individual clouds without any connection. It is easy to see that there are four, five, six, or more of them grouped together to form what might be called primary groups, which combine together to make larger figures. The quite irregular shape of these figures is marked by broad dark lines meandering through the groups of brilliant granules. They form a compact net of a true photospheric nature. Plate I shows a great number of these lines.

Are these broad or narrow dark lines identical in substance with that of the brilliant granules they are meandering through; or are they a part of the gaseous atmosphere in which the granules, or photospheric clouds, are floating? Young[1] writes: "They (the granules) are luminous clouds floating on a less luminous atmosphere." Secchi[2] says: "Les grains paraissent comme suspendus

[1] *Textbook of General Astronomy* (revised edition, p. 196).

[2] *Le soleil* (2e édition, 1re partie, p. 52).

PLATE III



Details of Photospheric Structure

dans un réseau noir et entremêlés de nœuds plus ou moins sombres, plus ou moins larges." That the granules are clouds of condensed particles, either liquid or solid, seems unquestionable, but that the darker lines consist of a gaseous atmosphere in which the clouds are floating is not so evident. They may be as well formed of the same particles, less luminous only because, being at a lower level, they are covered with a thicker stratum of chromosphere and reversing layer. With all respect to the high authority of Young and Secchi, I think the latter view is more consistent with the aspect of the photosphere on photographs, as well as with spectroscopic observations. On the photographs the photosphere looks like an extended and unbroken layer. It must be formed of condensed particles of many of the substances composing the gaseous mass of the sun. The external surface exposed to our sight, far from being plane and uniform, presents an aspect much like the fleecy form of our alto-cumulus clouds.

Here arises a question the solution of which would be of great interest, viz., are the granules always of the same form; or are there various forms of photospheric clouds, just as there are widely different forms of atmospheric clouds? Secchi[1] gives three drawings of the photosphere, Figs. 21, 22, and 23 of his work, and says:

> La comparaison des différents dessins que nous reproduisons peut faire apprécier les différences d'aspect que présente la photosphère, suivant les époques où on l'observe, et peut-être suivant les observateurs et les moyens qu'ils emploient.

In this last sentence, Secchi took a very wise stand. In fact, if the differences of the drawings represented true changes in the photosphere it would be evident that there are photospheric clouds as widely different from each other as our various kinds of clouds. But very probably, and, I dare say almost certainly, they are merely differences of clearness of the images at the focus of the refractor. I could easily produce photographs showing as much difference in the photosphere, but never with the same clearness of the images. Whenever the plate does not show the granules distinctly there is on the plate a lack of clearness, which becomes evident when examined with a powerful lens, or when enlarged to 20 or 30 diameters. In such cases, on account of a disturbed atmosphere, merely the primary

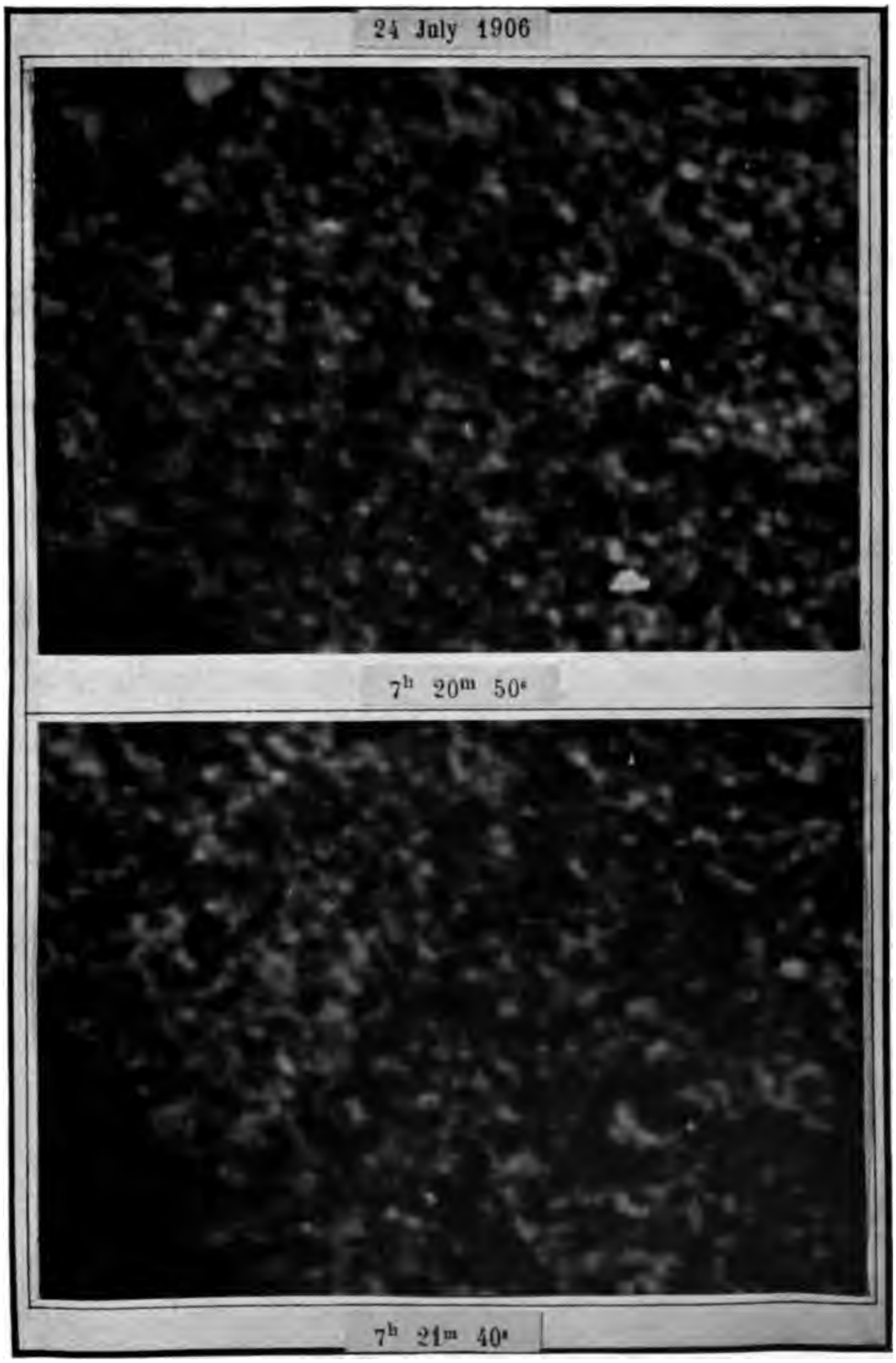
[1] *Loc. cit.*

groups of granules, or even the larger groups alone, are brought up on the photographs. Whenever the photograph is very clear it exhibits a photosphere very nearly the same in its general aspect as the photosphere of any other day, and the differences are not easy to grasp and describe clearly. It is supposed that the granules are now more circular, now more elliptical, sometimes larger, sometimes smaller. I also surmise some systematic differences in the grouping of the granules as well as in the form of the meandering dark lines of the photosphere. But I have not come to any definite conclusion. This field of investigation is new and difficult. We hope to be able to give it more attention.

Duration of the granules.—The time that elapses between the formation of a granule and its disappearance is very short. After only ten minutes or so nothing remains that can be recognized on the surface of the sun except spots and faculae. I have compared photographs taken at intervals of seven minutes, and not a single granule of the first could be found on the second. But there were still several features of the broader dark lines, several of the larger groups of granules which, though much altered, could still be recognized, as remains of the photospheric clouds brought out on the first photograph. On comparing other plates taken at an interval of two minutes and a few seconds, I found that although many groups of granules were changed in form, most of their features were still easily recognizable and the individual granules had not yet all disappeared.

The two photographs of July 24, on Plate IV, were made at an interval of 50 seconds. Quite a number of individual granules are found on both, with hardly any change. Some are altered in their shapes, some are more conspicuous on the first plate and have grown fainter or smaller on the second; some, on the contrary, have gained in size. On account of the differences in the plates themselves, the recognition of the real changes in the granules requires much attention. As to their explanation, my impression is that some granules look brighter or larger simply because they have risen to a higher level, while others have sunk down, and consequently have become less brilliant. We cannot say how far this rapidity of formation and change is constant. Is there any connection between the periodical activity of the sun and this rapidity of change in the photosphere?

PLATE IV



DETAILS OF PHOTOSPHERIC STRUCTURE

This is an unexplored field of research which promises results of real interest.

Horizontal movements of the granules.—In the paper already referred to, M. Hansky paid a great deal of attention to this subject, and excited the widest interest in declaring that the granules of the photosphere were moving on the surface of the sun with enormous velocities reaching to 40 km a second. I was the more interested, as I was at the time engaged in a study of the photosphere. I easily realized how necessary it was to take up the important research so admirably initiated by M. Hansky, and included in my studies the measure of the movements of the granules. I give my measures with all reserve, as it is very difficult to reach any accuracy in measuring the displacement of a granule. Indeed the displacement to be measured is small relatively to the diameter of the granules, which are, moreover, inconstant in shape, while their edges, and consequently their centers, are far from being well defined, with the result that there is a complete want of a fixed point. On the other hand, in computing the velocity of the granules, the error of measurement is divided by 30 or 50, the number of seconds elapsed between the two photographs—a circumstance which makes it possible to obtain a better determination. I think it best, therefore, to explain how I endeavored to get as fair measures as possible, and how the values obtained were tabulated. A few conclusions will then be given.

For each pair of photographs I first made two positive plates, and looked for all the granules which were perfectly definite on both. On each plate I marked with a red dot the center of each granule. Having so marked many granules, I superposed the plates, trying to obtain as fair an agreement of the granules, throughout the two plates, as I could. Taking every care to avoid parallax, I marked on the upper plate the red dot of the lower one, wherever it did not prove coincident with the upper one. I then took away the upper plate on which the horizontal movements of the granules were shown by the distances between the red dots. The plates were examined again to see whether some slight error had been made in pointing the centers, and the distances of the red dots could be attributed to such errors. In several instances where the displacement was very

small, it might easily have been so; as also, where the centers had been considered as coinciding, a very small displacement was not altogether impossible. But I was satisfied that the distances I had obtained were, on the whole, as close an approximation to the truth as could be hoped for. Micrometric measures would have been easy but to no purpose. The distances were consequently measured to one or two tenths of a millimeter with a millimetric rule and the help of a magnifying glass.

To transform the resulting distances into kilometers, I made the half-diameter of the sun equal to 697,130 km and 15′ 46.″7 at the end of July. In consequence, one millimeter in the center of the disk will be equivalent to 670 km. As the part reproduced here is sufficiently near the center, we may use this value throughout the three pairs of photographs. Besides these three pairs of photographs, another one obtained on October 13, 1906, was also measured after the same method. This was chosen rather distant from the others, to see whether any considerable difference could be found. For this last plate the value of a millimeter has been made equal to 656 km.

The following table gives the results and contains, with the dates and the time elapsed between the two photographs, the number[1] of granules measured, the number of granules found to have no movement, the maximum displacement measured and corresponding velocity per second, with the number of granules having reached this velocity. I have added in the last two columes the mean of the displacements measured, and the mean resulting velocity. The mean of so widely different members is in a way meaningless; but it is intended to give, with the number of motionless granules and the maximum displacement of a single granule, some idea of the average

Dates	Time Elapsed	Granules Measured	Motionless Granules	Maximum		Granules	Mean	
				Displacement	Velocity		Displacement	Velocity
				mm km	km		mm km	km
July 20, 1906	30^s	46	9	1.1 = 836	33	1	0.34 = 228	9
July 21, 1906	29	38	12	1.1 = 836	28	1	0.41 = 273	8
July 24, 1906	50	54	12	1.5 = 1005	20	1	0.67 = 449	9
Oct. 13, 1906	30	54	25	1.2 = 787	26	1	0.36 = 236	8

[1] The plates measured are much larger than the present photographs.

of the displacement measured, without printing a full table of the measures which do not seem to be of any importance.

The maximum velocity reached by a few individual granules agrees fairly well with those measured by M. Hansky. But the mean velocity is so much lower, and there are so many granules which do not move at all, that the tremendous velocity obtained for several granules seems to be suspicious. The quantities to be measured cannot be, indeed, defined more accurately than to 0.1^{mm} or 0.2^{mm}, which represent 2 and 4 kilometers. But these are low figures compared to those of the maximum velocities, which consequently cannot be due to errors of measurement.

But whatever the inevitable inaccuracy of the above figures, it does not affect the conclusions which, I think, can be expressed as follows:

1. If any portion of the photosphere be compared on plates taken at a minute or a half-minute interval, most of the granules will be found substantially the same and perfectly recognizable.

2. These granules have generally, however, experienced many obvious changes as to their shape and brilliancy.

3. On looking more attentively it is found also that many of them have changed their relative positions.

4. The displacements of the various granules differ widely, ranging from zero to thirty or more kilometers a second.

5. These displacements are as widely different in direction as they are in velocity, each granule going its way without relation to the movements of others in its neighborhood.

6. The displacements observed in several granules reach sometimes to enormous figures when expressed in kilometers, but they are small if compared with the diameter of the moving granule. In fact no granule, I think, during the course of its existence moves so much as the length of its diameter.

The question now arises whether we are contemplating true movements along the surface of the sun, or mere changes of shape and form in the granules, by vertical motion of the condensed particles. If it be supposed that the granules are luminous clouds floating in a less luminous atmosphere, as clouds in our atmosphere, and it is found that they are moving through this atmosphere, or with it, at

the tremendous velocities of 20, 30, 40 kilometers a second, we are certainly in the presence of a most important phenomenon. But this supposition does not seem consistent with the above conclusions. Such enormous horizontal velocities of some granules, in the neighborhood of which there are other similar granules which do not move at all, or move in different directions, and at different rates, seem to be almost beyond comprehension.

Let us admit, on the contrary, that the granules are the summits of a fleecy stratum of condensed particles, with or without any horizontal movement; and that the stratum is subject to undulatory movements; the summits of the waves will then present the same succession of changes; their relative position varying in every direction and with any velocity. The short, quickly changing waves of a choppy sea may possibly give us a faint imitation of what is realized on a gigantic scale and in a very different element in the solar photosphere.

ZÔ-SÉ OBSERVATORY
Près Zi-ka-wei, China
Oct ber 1907

ON TWOFOLD LINE-SPECTRA OF CHEMICAL ELEMENTS[1]

By E. GOLDSTEIN

In recent years I have been led to investigate the emission spectra of a number of elements, particularly the alkali metals and the halogens, more thoroughly in some directions than has hitherto been done.

In the course of these researches I have found that caesium, rubidium, and potassium each possess two line-spectra which do not have a single line in common. Differentiation of the two spectra is not effected simply by inference, but is accomplished experimentally. Under certain definite experimental conditions one may obtain solely the lines of the one spectrum or solely those of the other; the one coincides with the arc-spectrum of the metal in question, but may also be produced by weak electric discharges; the other is evoked distinctly by heavy discharges from a condenser.

A number of the lines of the new spectra had already attracted attention: several of the new potassium lines were observed by Lecoq de Boisbaudran,[2] but were assigned by Kayser and Runge[3] to suspected impurities. Similarly a number of these lines occurred among those observed by Eder and Valenta;[4] and for rubidium and caesium in those of Exner and Haschek[5] from the ultra-violet to the blue (about λ 460). But in these investigations also the new lines appear on the use of discharges from jars only in addition to the long-known lines of the elements, so that from them the only conclusion which could be drawn was that the arc-spectra of the alkalies mentioned were enriched by a number of lines on employing the spark from condensers; while the arc-spectra persist.

[1] A preliminary communication to the Deutsche physikalische Gesellschaft, dated August 14, 1907. Translated from *Verhandlungen*, 9, Nos. 15, 16.

[2] *Spectres lumineux*, Paris, 1881.

[3] *Abhandlungen der Berliner Akademie*, 1890.

[4] *Sitzungsberichte der Wiener Akademie*, June 1894.

[5] *Wellenlängentabellen*, Leipzig und Wien, 1902.

The methods I have employed, to be described in a more extensive communication, in effect consist in raising the density of the discharge, referred to the mass unit of the metallic vapor, decidedly beyond the previous limits. With an adequate increase in this respect it is observed that the long-known lines of the three metals entirely disappear, while new lines appear in great brightness which coincide with no arc lines. Inasmuch as the arc lines of the alkali metals are all series lines, while the new lines fit into no series, we may therefore make for these three metals the statement: ***Powerful discharges extinguish all the series lines and replace them by non-series lines.***

The color of the discharge changes very strikingly in the transition from one to the other spectrum: for instance, for rubidium it changes from a rose red (series spectrum) into a brilliant sky blue; in the case of caesium, from a bluish red into a greenish gray-white.

The strengths of the discharges necessary to cause the lines of the new spectra to appear increase in succession from caesium through rubidium to potassium. They are therefore greater as the atomic weight is smaller (*Cs*, 133; *Rb*, 85; *K*, 39). In the case of sodium (atomic weight 23) I have hitherto succeeded only in producing a very decided weakening of the series lines, but not in extinguishing all the series lines and replacing them by a new spectrum; for lithium (atomic weight 2) the effect is the least. In respect to the effect of the atomic weight mentioned, the suspicion seems to me permissible, however, that with experimental conditions permitting a further increase in the density of the discharge, the long-known sodium spectrum would also disappear in all its series and be replaced by a new one. The same thing may be suspected for lithium.

If two wholly different line-spectra are to be ascribed to the alkali metals (thus far to *Cs*, *Rb*, and *K*), this result departs pretty widely from the original assumptions in spectroscopy, and the question suggests itself whether a support for this is found in our experience in other directions. We may point in this respect to some of the new monatomic gases, in which similarly twofold line-spectra are observed, namely, in argon, krypton, and xenon. We further recall the beautiful research in which Lenard[1] showed for the alkali metals that different

[1] *Annalen der Physik*, 11, 636, 1903; 17, 197, 1905.

particles may radiate differently in the electric arc, emitting either the principal series only or one of the subordinate series, according to their temperature.

The most obvious assumption in view of such behavior appears to me to be that the metallic vapor in the arc forms different isomeric (or polymeric) aggregations according to temperature, and that to every aggregation a particular series of vibrations corresponds, the type of which remains the same, however, for the different aggregations of the same element. In support of such an assumption, perhaps the observations[1] may serve which have been made on the discontinuous emission spectra of solid organic bodies in which isomeric substances (for instance, the three xylols) exhibit an identical spectral type (form of grouping of the maxima), but have different wave-lengths of the comparable maxima. In these bodies only a single type of structure, the ring of six members of the aromatic group, is capable of furnishing such regular phosphorescence spectra consisting of narrower or broader bands. If the ring is broken on forming other configurations, the regular spectra cease and a continuous emission only remains.

It may be that the association of the particles in different and regular groupings is a prerequisite[2] also for the regular gaseous spectra (band-spectra and series spectra). If these regular structures are destroyed by excessively powerful forces (condenser discharges) and separated into single particles, the regularly constructed spectra also disappear and only the non-series lines occur, which therefore would properly be the ones corresponding to free or isolated gas particles.

It may be permissible to distinguish these spectra belonging to most elementary conditions by a name, and designate them as the "fundamental spectra" ("Grundspectra") of the substances in question.

For slight intensities or densities of the discharge, therefore, only groups of gas particles would be luminous; for moderate intensities

[1] E. Goldstein, *Verhandlungen der phys. Gesell.*, 6, 156, 185, 1904.

[2] Such groupings may be caused in various ways, as for instance by ionization. The view that a material disintegration is connected with the ionization of gas particles is apparently giving way more and more to the view that associations occur with ionization. The last investigations by J. J. Thomson yield a threefold mass of hydrogen atoms for ionized hydrogen particles.

of the discharge a portion of the combination would be split up and the two spectral types would appear superposed, corresponding to the mixture; with the most powerful discharges only isolated particles would exist with the fundamental spectrum. The previous investigations of the alkali metals by Lecoq, Eder and Valenta, Exner and Haschek, and others, were made at moderate intensities, which were strong enough to split up a portion of the combination and thus permit the appearance of the lines of the fundamental spectrum in addition to the series lines of the remaining portion of the combination; while they were not strong enough to break up all of the groups and thus to extinguish the series lines. Tables and drawings of the fundamental spectra of caesium, rubidium, and potassium are to be published later, based upon the photographic plates. In this communication only the positions of the brightest maxima will be given. The brightest lines of the fundamental spectrum of caesium have the following wave-lengths:

λ 592.8	525	487
583	523	483
556	505	466
537	497	460.3
535	495.5	

The bright caesium lines at λ 459 and λ 455, which are so characteristic of the arc and flame spectrum, are invisible, as are all the remaining lines of the series spectrum. The number of the fainter lines is considerably larger. The caesium spectrum extends beyond $H\alpha$, forming in the red from about λ 600 to λ 645 a series of numerous and closely packed although not specially bright lines.

This renders more striking the scarcity of lines in the red portion of the fundamental spectrum of rubidium, the series spectrum of which is characterized by several very bright lines just in this region. The bright lines of this fundamental spectrum do not begin until the green is reached, and its brightest lines are:

λ 552.6	453
515.2	429.5
477.7	427.3
457.6	424.8

Potassium has in the red portion two bright lines at λ 624.5 and 630 in addition to the line at λ 611 previously noted by Lecoq. The less bright lines will be communicated later. Lecoq also observed several lines of the fundamental spectrum in the green and blue mixed in with series lines. The brightest lines of this potassium spectrum are at wave-lengths:

λ 630	483	439	418
624.5	461	431	415
611	451	426	413
501	447	422	411

For comparison I add the principal lines of the series spectrum of potassium:

λ 770	581	532
767	580	404.7
694	578	404.4
691	536	
583	534	

The suspicion naturally arises that the occurrence of different line-spectra for one and the same element may not be limited to the alkali metals (and several monatomic gases). There are in fact several indications that we are here concerned with a more generally extended property, although nothing definitive can be stated at present. For a long time strong differences have been known to exist between the arc-spectra and spark-spectra of different metals. If, for instance, we compare tables or photographs (such as Hagenbach & Konen's *Atlas der Emissionsspektren*) of arc and spark spectra of silver, zinc, cadmium, copper, and mercury, we find a number of lines which are more or less weakened or extinguished, in the transition from the arc, as has already been pointed out by numerous writers. But in this transition by far the greater portion of the lines appearing in the arc always remain and *increase* in brightness.

If therefore the two line-spectra should be assigned to these metals (other metals exhibit similar properties), then both spectra would appear mixed in together at the slightest density of discharge hitherto applied, or at the lowest temperature. They cannot be experimentally separated until the spectrum can be reduced to a number of lines at a relatively low temperature, which are all suppressed at a

high temperature (heavy discharge) and are replaced by lines in other positions. Until then the two spectra from these metals could be separated only as a matter of theory. In this manner J. Stark[1] has actually assumed that two line-spectra exist for mercury. For the view that the twofold line-spectra represent a widely diffused property, it seems to me confirmatory that it occurs in the case of elements which stand as far away from those hitherto treated, as is the case for the halogens, although not in so pronounced a manner as for the alkalies, but more obviously than for the other metals just mentioned.

A closer study of the halogens according to the process which I sketched long ago[2] leads to this view. This process, as was then explained, enables us to produce the band-spectra of bromine and chlorine. The more thorough investigation which I have just completed now yields the result that a series of lines are superposed over these band-spectra somewhat as the four-line spectrum of hydrogen overlies its band-spectrum. If powerful discharges are now passed through tubes of bromine and chlorine the greater portion of those lines become invisible,[3] while another portion of the lines becomes bright, and furthermore, new lines become brightly luminous. Overlying the band-spectrum of diluted bromine appeared the following lines:

TABLE I

λ	Int.	λ	Int.	λ	Int.	λ	Int.
782	1	640	2	539.5	2	475.6	2
753	3	635	6	534.7	2	472	1
735	3	629	1	530.8	2	470.7	4
727	1	628	1	524.2	5	468	2
716	2	620	2	518.2	5	461.5	2
711	2	617.5	2	517	2	457.6	4
700	4	615.3	1	505.5	1	451.5	3
678	4	615	6	498.3	5	452.6	3
673	2	613	2	493	2	448	4
668.5	2	610	1	492.5	2	447.5	4
667	2	585	2	482	4	444.2	3
663	5	577.8	2	478.5	5	436.3	2
655	1	559	2	478	5	422	2
654	5	547	2	477.2	1		
648	1						

[1] *Annalen der Physik*, 4, 16, 490, 1905.

[2] *Verhandlungen Berliner Phys. Gesell.*, 1886, p. 38.

[3] Hazy traces appear on long exposures in case of the strongest of the lines which are extinguished to the eye. A further increase in the intensity of the discharge would presumably also extinguish these traces.

The intensities are estimated on a scale of 6 steps, where 6 represents the greatest brightness. Of these lines, the following disappear on connecting in the Leyden jar:

782	668.5	585	457.6
753	667	577.8	452.6
735	663	547	451.5
727	655	539.5	448
716	654	534.7	447.5
711	620	498.3	444.2
700	617.5	478	
678	615.3	475.6	
673	615	461.5	

There were not included in the above tables several lines for which it remained uncertain whether they persist or whether they are extinguished and replaced by new lines very close to their positions.

Thus at least 33 of the 56 lines are extinguished by the jar.

What we have hitherto regarded as the spectrum of bromine is a mixture of lines which may be extinguished and of the lines of the fundamental spectrum. The occurrence of the mixture depends, as in the case of the alkali metals, upon the fact that in the previous investigations the density of the discharge (referred to the unit of mass of the gas) could not be sufficiently great, for reasons to be presently mentioned. The discharge tubes used had electrodes which gradually absorbed the gas, forming bromides or chlorides, even for slight intensities of the discharge. Therefore the tubes could not be filled at a low density. But intense discharges (of the Leyden jar) were wholly excluded, because then the absorption by the electrodes would take place in a fraction of a minute. Hence it resulted, under the conditions of the experiment which practically had to be employed, that the densities of discharge were such that a number of the lines given in Table I were extinguished and therefore necessarily remained unknown; while these intensities of discharge were able to weaken a series of other particularly bright lines only to such an extent that they could be cited in the previous lists of lines of bromine as the principal characteristic lines. For instance, among these belong the following bright lines which have hitherto been regarded as characteristic for bromine:

λ 699, 615, 452.6, 448, 447.5, 444.2.

A sufficient increase of the intensity of the discharge makes them all invisible.

In the case of chlorine 24 lines were extinguished in this manner, which appear when the capacity is not used. The brightest of these chlorine lines which are suppressed at even moderate intensities of the discharge are:

$$\lambda\, 753,\ 741,\ 725,\ 614,\ 466,\ 461,\ 453,\ 439.$$

It has not been possible hitherto to establish a perfect agreement with the behavior of the alkali group, as pointed out above; since in case of the alkali metals, *all* of the lines which appear together under certain conditions may be extinguished, but in case of chlorine and bromine only a considerable number of them. In case two wholly different line-spectra exist for chlorine and bromine, their complete separation has therefore not yet been experimentally accomplished. Groups which can be extinguished, however, appear to be purer as the width of the tube is increased, or therefore, other things being equal, as the density of the discharge is less (which is also true of the luminous intensity). The investigation will be continued in this direction.

The investigation of iodine for the presence of two line-spectra is rendered difficult by the fact that the brightness of the background changes very greatly on throwing in the jar, so that judgment as to the change of brightness of many of the lines is rendered uncertain. It could be recognized, however, that a number of lines which are suppressed in the band-spectrum of iodine, e. g., λ 524, 520, 512, 491, differ decidedly in their behavior from many other lines.

These investigations establish for the first time the forms assumed by the spectra of chlorine and bromine when these gases in an attenuated condition are traversed by powerful jar discharges. Earlier investigations were frustrated by the above-mentioned action of the gases on the material of the electrodes. The tubes which I employed were coated with tinfoil on their external surface only. There seems to be a widespread belief that powerful condenser discharges cannot be passed through such tubes with external coating, but this supposition is incorrect. Such a tube can be connected in parallel with a jar just as an electrode tube. If an air-gap is then inserted in

the circuit leading to the internal coating of the jars, powerful condensed discharges of great brightness will pass through the tube, which also differ in the altered color of the discharge from those which pass through the tube when a jar is not used. The color of the discharge thus changes for bromine from peachblow into greenish blue, for chlorine from white to green, for iodine from chamois yellow to green.

Such condenser discharges in passing through the halogens give spectra exceedingly rich in lines which may be observed with very slight density of the gas as long as may be desired without any development of combinations by the gas or alterations of its density. The spectra thus far exceed in the number of lines those hitherto photographed for chlorine and bromine. The most complete representation of the chlorine spectrum hitherto produced is due to Eder and Valenta.[1] They cite in all 110 lines between λ 546 and λ 400. On plates of the same region I obtained twice as many lines, even with the relatively slight dispersion of a single Rutherford prism, which permitted many doubles and close groups to appear as single lines. The increase in number of lines is similar in the case of bromine.

The process I have used gives especially striking results in the least refrangible portion of the spectrum. Plücker and Hittorf[2] record 5 lines for chlorine from the extreme red to λ 600, or 16 lines in all to λ 546. (The observations of Eder and Valenta begin in the yellow.) My plates give 34 lines in all to λ 600, and more than 80 to λ 546.

For bromine the farthest line to the red hitherto was the line observed by Salet at λ 699; five other lines were observed by Salet in passing to the yellow. Eder and Valenta give λ 668 as the farthest line and 15 others to λ 600; my observations show that the condenser spectrum of bromine extends beyond λ 700, and that from its extreme limit to λ 600 it consists of a closely packed series of several dozen lines, of which a portion become somewhat diffuse with intense discharges. Visual observations show still more lines than the photographic plate in this closely packed series, because with the relatively small dispersion on the plate the neighboring lines often coalesce.

A description of the most suitable dimensions of the tube and

[1] *Sitzungsberichte der Wiener Akademie*, April 1899.

[2] *Phil. Trans.*, 155, 1, 1865.

technical particulars as to the mode of filling them will be given in a more extended paper, in which I shall also give another description of the spectra of the halogens. These discoveries as to double spectra and the assumptions indicated above as to the origin of the series-spectrum, suggest a number of conclusions, as well as new investigations.

If the series spectra in fact depend upon association of gas particles into complex groups, then it would seem to be theoretically possible that all such groups could be experimentally broken up and thereby the fundamental spectra of the isolated particles could be obtained. On this basis entirely new spectra could be expected, for instance in the cases of hydrogen and helium. We cannot regard such suspicions to be contradicted by the fact that these two gases have already been often investigated with discharges of great density. The atomic weight might here also be influential, and if the appliances which are effective for large atomic weights already fail at an atomic weight of 23, then elements with atomic weights of 4 and 1 might oppose a very much greater resistance to the breaking-up of the complex groups. There is possibly also a connection with the fact that xenon, krypton, and argon, with atomic weights of 128, 82, and 40, respectively, exhibit twofold line-spectra, while for neon (atomic weight 20) only one spectrum has thus far been observed.

Another investigation suggested would be to see whether the apparent absence of potassium, rubidium, and caesium from the sun might be due to the appearance of their fundamental spectra among the Fraunhofer lines in place of the series-lines which have hitherto alone been looked for. I hope to be able to test this soon in a more suitable place than in my almost sunless laboratory.

Other questions which are raised by the twofold line-spectra refer to their behavior in respect to the Zeeman effect, to the possible charge of the carriers of the line, to the behavior of the lines in regard to Doppler's principle, etc. These questions are so obvious as to make further discussion of them superfluous for the present.

BERLIN

OBSERVATIONS OF *SATURN'S* RINGS AT THEIR DISAPPEARANCES IN 1907 WITH A SUGGESTED EXPLANATION OF THE PHENOMENA PRESENTED

By E. E. BARNARD

The interest in the beautiful ring system of the planet *Saturn* has never been greater than in the present year, when, according to calculation, the ring has been invisible. It is well known that at intervals of fifteen years the edge of the ring is presented to us and it is then supposed to disappear because of its extreme thinness. Two causes operate to produce these disappearances: first, when the plane of the ring passes through the earth; and, second, when it passes through the sun. It is possible for the ring to make two disappearances and two reappearances during this critical period. Thus in the years 1861–62 the ring twice disappeared and reappeared. Previous to this the sun and the earth had been on the south side of the ring for fifteen years. On November 22, 1861, the earth passed through the plane of the ring going north and until January 31, 1862, the earth and the sun were on opposite sides of the ring, and it was supposed to be invisible in the interval. On January 31 the earth again passed to the south side of the ring and it once more became visible, for the sunlit surface was then turned to the earth. On May 17 the sun passed through the plane of the ring, going north, thus leaving the earth once more on the dark side of the ring, which was invisible until August 12, at which time the earth passed to the north and was again on the sunlit side, where both the sun and the earth remained until 1878.

A valuable series of observations of *Saturn* was made with the 15-inch refractor of Harvard College Observatory by G. P. and W. C. Bond at the disappearance of the ring in 1848. These make part of Vol. I of the Harvard College Observatory *Annals*.

A number of the many drawings of *Saturn* given in that volume show the ring and condensations essentially as they have appeared during the past few months.

The conditions for the disappearances and reappearances of the ring in 1848 were almost identical with those in the present year. The earth passed the plane of the ring in April, going south. On September 3 the sun passed the plane going south. On September 13 the earth passed back north, and on January 19, 1849, the earth once more went south with the sun. Therefore between April and September 3, the earth and sun were on opposite sides of the ring. This was again the case between September 13 and January 19.

Bond assumed in all his observations that what he saw was the sunlit edge of the ring. He was not therefore forced to any unusual method to explain its visibility. It takes but a moment on a good night at present with the 40-inch telescope to see that in reality what is visible is not the edge but the extremely oblique surface of the ring itself. This was especially so in the observations in the first part of July, when the minor axis of the ring was about $2''$. His explanation therefore cannot be the true one.

Bond's explanations of the bright markings, condensations, or knots, seen on the ring during part of its "invisibility" is an ingenious one, and is seemingly confirmed by his measures. Though his explanation may in part have something to do with the phenomenon, it is not entirely satisfactory. The thickness of these condensations, even allowing for irradiation, is entirely too great to assume that they are due to the edge of the ring, which must be much less than $0''.1$ in width.

The circumstances of the disappearances in 1861–62 were very favorable for observation. Advantage was taken of the opportunity to study this interesting phase of the ring at Greenwich by Mr. Carpenter with the 12-inch refractor, and at Pulkowa by Otto Struve with the 15-inch. At this time when the ring was theoretically invisible it could readily be seen. Luminous appendages were visible on it both at Greenwich and Pulkowa, when it was not illuminated by direct sunlight. Since then, during an interval of 45 years, no favorable opportunity has presented itself to reobserve the phenomena seen by the Greenwich and Pulkowa observers in 1861–62. The disappearances of 1878 and 1891 occurred under very unfavorable conditions, as the planet was too near the sun in each case to be satisfactorily observed. In the last case *Saturn* rose about two

hours before the sun. In both those years there was only one disappearance and reappearance.

In the present year—1907—there has been a repetition of the disappearances and reappearances of 1861–62. After 1891 the sun and the earth were on the north side of the ring.

The following information concerning the present disappearances is due to Professor Hermann Struve (*Proceedings of the Astronomical Society of the Pacific*, **19**, 125–35, June, 1907).

April 17, 1907: The earth passed through the plane of the ring to the south side, leaving the sun on the north side. This disappearance could not be seen from the earth, the planet at that time being lost in the sun's rays. From this date until July 26 the ring was supposed to be invisible, as no direct sunlight reached its earthward surface. On July 26 the sun also passed to the south and the ring again became bright. This condition continued until October 4, when the earth once more passed to the north and will remain on the dark side of the ring until January 7, 1908, when it will again pass to the south and the sunlit side of the ring will be visible for the next fifteen years.

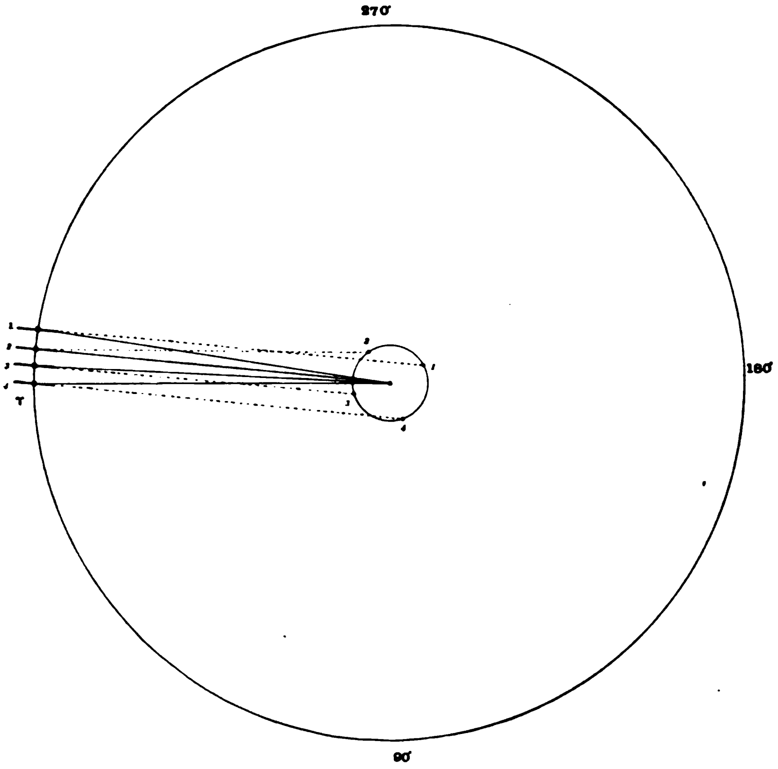
On account of the circumstances of the disappearances and the fairly favorable position of the planet, this was the first opportunity for such observations to be made with the great telescopes of the world, for in the past 45 years they have all come into existence.

When I examined *Saturn* on July 2 the entire surface of the ring was distinctly visible. No direct sunlight was then falling on its earthward surface. On each ansa were two conspicuous luminous places or condensations. These were symmetrical with respect to the ball. In appearance they were very nebulous, the light of the ring and the condensations being of a pale ashy or nebulous color. The positions of these luminous appearances were measured with the micrometer. Repeated measures have not shown any change in their positions.

On July 26 the sun passed the plane going south, and until October 4 it was shining on the visible surface of the ring. During this period the ring was bright and linear and no irregularities were visible upon it where the condensations had been seen.

On October 4 the earth passed back to the shadow side of the

ring, and for some days thereafter the ring was perfectly linear. The apparent condensations had disappeared at a time when they should have been best seen if they were real masses on the ring system. On



The diagram shows the relation of the orbit of *Saturn* and the earth drawn to scale. I have indicated the positions of the earth and *Saturn* and his ring at the critical times for the disappearances, etc., in 1907. 1–1 are the positions of the earth and *Saturn* on April 17; 2–2 the same for July 26; 3–3 the same for October 4; 4–4 the same for January 7. It is hardly necessary to call attention to the fact that between the positions 1 and 2 the earth is on the shadow side of the ring, and from 2 to 3 it is on the sunlit side, while from 3 to 4 it is once more on the shadow side.

October 13 they had again appeared, but were only very slightly luminous thickenings on the ring. After that they became more and more conspicuous as the ring opened out by the elevation of the earth above its north surface. This amounted to nearly a degree

in the latter part of November, at which time the sun was some 2° south of the plane.

I have assumed the following interpretation of the phenomena of the bright condensations and of the visibility of the ring. What we really saw in July, and in October and November, when the sun was on the opposite side of the ring to us, was the feebly luminous surface of the ring itself at a very oblique angle—where the angular diameter was reduced to a second of arc or less; at the observations in July it was 2″ in diameter. As this surface was visible without the aid of the direct sunlight, the natural assumption would be that the ring is self-luminous. Its physical constitution, however, forbids this supposition. It is well known that the crape ring is transparent and that it transmits sufficient sunlight to make a satellite visible while in its shadow. This was shown at the eclipse of *Japetus* on November 1, 1889, when the satellite was seen throughout the entire extent of the shadow of the crape ring, which at most cut down the brightness about one magnitude. The ball of the planet is readily seen through this ring when the rings are opened out wide. This transparency, and the duskiness of the ring on the sky, are undoubtedly due to a scarcity of the particles which compose it. The other rings are bright because they are made up of a vastly greater number of small bodies to reflect the sunlight. That these rings do not transmit a great amount of light was proved at the eclipse of *Japetus* already mentioned, for when the satellite entered the shadow of the bright rings it completely disappeared. This does not mean, however, that the rings are entirely opaque to the sun's light. Though they are translucent, they are not transparent in the ordinary sense of the word, for the planet cannot be seen through them where they cross the ball.

This brings us to a probable explanation of the phenomena of the condensations which have been visible on the dark side of the rings. Knowing that the crape ring is transparent, if we were to look at its under side—the opposite side from the sun—at an oblique angle we should still see it luminous by the reflection of the sunlight in our direction from the small bodies composing it. The illumination would be nearly as strong as when seen from the sunward side. From the extreme thinness of the rings, which must be greatly under 100 miles (60 km), and more probably less than 50 miles, the par-

ticles cannot form an impenetrable screen to the light of the sun. That is, the sunlight will sift through among them, and by diffusion and inter-reflection and scattering will make the rings visible from the dark side. We should therefore expect to see the entire surface of the rings at this time by the percolation, scattering, and reflection of the sunlight through them. One might expect under these conditions that the brighter portions of the ring would appear dark when so seen by cutting out more of the sunlight through a greater number of particles. This, however, up to a certain point of density would not be so; it would in reality be just the reverse. In the case of the crape ring it would appear faint—as it does always—because of the fewer particles to reflect the sunlight. Where they are more densely packed, as in the bright rings, there would be a relatively greater amount of scattering, reflection, and diffusion of the light and they would therefore appear relatively bright.

It is apparent to any observer of *Saturn* ordinarily, with a telescope of sufficient power, that the outer one-fourth of the inner bright ring is much the brightest part of the entire ring and ball system; the inner portion of that ring being of the same brightness as the outer ring which is uniformly illuminated. Let us therefore see where these condensations fall upon the projection of the rings. I have repeatedly measured with the micrometer their positions since the first of July.

It is perhaps appropriate here to give the dimensions of the ring and ball system of *Saturn* as measured by the writer in 1894–95 and with them the positions of the condensations as they may be useful to others in connection with the problem. They are all reduced to the mean distance of *Saturn* from the sun = 9.5389. (See *Monthly Notices*, **56**, 171, 1896.)

Equatorial diameter of *Saturn*	17″800	Radius	8″900
Outer diameter of outer ring	40.108		20.054
Inner diameter of outer ring	35.046		17.523
Center of Cassini division	34.517		17.258
Outer diameter of inner ring	33.988		16.994
Inner diameter of inner ring	25.647		12.823
Inner diameter of crape ring	20.528		10.264
Width of Cassini division	0.529		
Inner condensation preceding	2.675 from the limb or		11″575 from center
Outer condensation preceding	7.457 from the limb or		16.357 from center
Inner condensation following	2.737 from the limb or		11.637 from center
Outer condensation following	7.420 from the limb or		16.320 from center

Though it does not enter into the present problem, the measured polar diameter of *Saturn* was 16″.241.

A glance at the figures will show that the outer condensations fall on the brightest part of the inner bright ring—the outer one-fourth of which, as I have already said, is very much the brightest part of the entire system of *Saturn*. The inner condensations apparently fall on the crape ring. In reality the ring system is seen almost on edge, so that the visible surface is very oblique. The crape ring may have nothing to do with the explanation of the luminous appendages for reasons previously given. But the projection of the bright part of the inner bright ring would fall in the same direction as the crape ring. It would seem therefore that this bright region of the ring is really accountable for both condensations. It is clearly so in the case of the outer ones. Why the space between the bright places should be almost discontinuous does not yet appear quite clear. It may be due to the curvature of the ring at this point where the sunlight might be less effective in diffusion and reflection by the greater depth of the ring there in the line of sight.

On December 12, 1907, I made the following additional measures of the condensations. The values are reduced to the mean distance of *Saturn* from the sun:

Length of outer condensation	2″.28
Space between the condensations	2.30

The measures of the positions of the condensations given in the table refer to their centers. Applying the above measures and those in the table, we have:

Distance from the center of *Saturn* to the outer edge of the distant condensations	17″.50
Distance to outer edge of Cassini division . .	17.52
Distance from the center of *Saturn* to extreme end of inner condensations	12.92
Distance to outer edge of crape ring	12.82

The accordance of the above measures has suggested another explanation of the phenomena of the condensations.

If the Cassini division is not free of particles, the sunlight shining

through among them would produce a luminous effect, as seen from the dark side of the ring, which would be represented by the position of the outer condensations. At the same time a similar illumination of the crape ring would produce the effect of the inner condensations.

Of course this is opposed to the generally accepted theory of the Cassini division, which considers it to be a zone in which no particles can exist owing to the action of certain of the satellites. This assumption would require that the Cassini division should be as closely filled with particles as is the crape ring, because the two pairs of condensations have been of equal brightness.

Though the condensations appear decidedly thicker than the projection of the ring in general, I think it is due to an irradiation effect, and that they are not any thicker than the trace of the ring on the sky: first, because they entirely disappear when the ring is really on edge—at a time when they should be most conspicuous; second, because in making drawings of the planet and ring as they now appear, I have reproduced the exact appearance by simply darkening the ring around the positions of the condensations without changing at all its outline. The eye is therefore deceived by the relative brightness of the condensations.

In the drawing of *Saturn* (Fig. 1, Plate V) I have endeavored to reproduce as exactly as possible the appearance of the ring and condensations as seen on December 12, 1907, at $17^h 0^m$ G. M. T. The same appearance, essentially, can be produced, as I have said, by leaving the excessively narrow elliptical outline of the ring unchanged, and by simply darkening it around the positions of the condensations. I have sent drawings of this latter kind in a paper to the Royal Astronomical Society, which I believe are the correct representation when the drawing is seen from the proper distance.

The present drawing should be looked at from a distance of about 3 feet to get the correct scale and appearance as seen in the 40-inch telescope with a power of 460 diameters.

Fig. 2 of Plate V is made from the measures given in this paper and represents a view of the system of *Saturn* seen from a position at right angles to the plane of the rings. The Lines *AA* and *BB* indicate where the condensations would fall by projection on the ring system.

PLATE V

South

FIG. 1
1907 DECEMBER 12, 11^h 30^m G. M. T.

FIG. 2
DIAGRAM OF THE RING SYSTEM OF *SATURN* SHOWING THE POSITIONS OF THE CENTERS OF THE CONDENSATIONS (*AA*, *BB*)

I will briefly describe the appearance of these luminous appendages as they were seen in the 40-inch telescope of the Yerkes Observatory (July, October, and November).

The full extent of the ring was seen as a slender line of light on each side of the planet. Symmetrically on these, both preceding and following, were two places of greater luminosity. The outer ones were elongated in the direction of the planet and were approximately $\frac{1}{2}'' \times 2''$. They were ill defined and more or less diffused, and seemingly were thicker than the ring. Beyond them the ring was very faint, but its entire length was seen. Between them and the ball were the inner condensations, which were approximately of equal brightness with the outer ones. These last, however, joined up to the ball with scarcely any lessening of brightness. Between the outer and inner condensations the ring was very faint but continuous. The condensations were quite bright and noticeable, but with a pale nebulous light. Frequent comparisons showed that they were decidedly brighter than either *Mimas*, *Enceladus*, or *Tethys* when these satellites were close to the condensations. Where the ring crossed the ball, its trace has not appeared black, and this is consistent with the supposition of the sunlight being transmitted through the ring.

The important fact clearly brought out at this apparition of *Saturn* is that the bright rings are not opaque to the light of the sun—and this is really what we should expect from the nature of their constitution, as shown by the theory of Clerk Maxwell and the spectroscopic results of Keeler.

During the present observations the ring was not lost entirely when its plane passed through the earth; though at the critical period of passing exactly the plane, it may have been invisible.

The question of the thickness of the ring again comes up at this time, for the opportunity has never been so good for the determination of this quantity. The favorable position of the planet and the powerful telescopes that are in use now would have greater weight than all the previous observations. On October 4, from $14^h 30^m$ to $16^h 0^m$ G. M. T., the ring was visible as a faint thin thread of light very difficult to see. The air was unsteady, and later, $17^h 40^m$ G. M. T., I could not see the ring. This latter fact, however, I attributed to the seeing having become worse. On the following night, October 5, $16^h 0^m$

G.M.T., it was distinctly visible. Whether it disappeared in the interval will require observations made elsewhere to decide. This may also be said of the interval closely preceding the observation of October 4. That the ring entirely disappeared is probable, for at no time during the period of its supposed disappearance could I see any trace of the sunlit edge, which should have been visible as a bright rim if the ring is of sufficient thickness to be seen exactly on edge.

YERKES OBSERVATORY
December 1, 1907

PRELIMINARY CATALOGUE OF LINES AFFECTED IN SUN-SPOTS[1]

REGION λ 4000 TO λ 4500

By WALTER S. ADAMS

INTRODUCTORY NOTE

One of the co-operative investigations set on foot by the International Union for Co-operation in Solar Research was the detailed visual study of the lines affected in sun-spots. The committee in charge of this work concluded that the simplest way to detect possible changes of intensity would be to compare the observed spot lines with the same lines as recorded in a map of the spot spectrum. The preparation of such a map from visual observations would obviously entail much time and labor. For this reason it seemed desirable to make use of the photographs of spot spectra obtained with the Snow telescope at Mount Wilson. Accordingly, a preliminary map was prepared and placed in the hands of the observers taking part in this work. The present paper is the first of a series which will contain a preliminary catalogue of the lines affected on the original negatives, and should prove of service in connection with the map.[2] Since the intensities in the catalogue are mean values, derived from the discussion of several negatives, they naturally possess greater weight than

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 22.

[2] It is perhaps desirable to emphasize the fact that in our previous publications on the spot spectrum we have made no attempt to give an exhaustive list of the lines affected in sun-spots for any region of the spectrum, but have treated merely some of the more prominent cases of strengthened and weakened lines. As an illustration of this it may be mentioned that in the region $H\beta$ to D a preliminary investigation indicates rather more than 225 lines which are weakened in spots. In a recent study of the same region Mr. Nagaraja of the Kodaikanal Observatory has given a list of 167 weakened lines (*Astrophysical Journal*, 26, 143, 1907). In this connection it may also be well to state that in our previous discussion of the weakened lines in the sun-spot spectrum on the temperature basis (*ibid.*, 24, 185, 1906), we have by no means maintained that all the weakened lines are spark lines. On the other hand, so far as our experience goes, it seems to be true without marked exception in the part of the spectrum extending from the red to λ 4000 that all spark lines are weakened. Mr. Nagaraja gives five lines in the region discussed by him which he considers exceptions to this rule. Of the first two of these lines, λ 5169.07 and λ 5169.22, it is the latter

estimates made directly from the map. It is expected that the detailed results from the individual plates will be published later, and it is also hoped that the preliminary map may ultimately be replaced by a more perfect one.

Although the instrument with which the negatives have been obtained, and the procedure followed in making the exposures have been described previously, it may be convenient for the purposes of reference to allude to them here. The spectrograph used was of the Littrow or auto-collimation type with a focal length of 18 feet (5.5 m) and having a 4-inch (10.2 cm) grating with 14,438 lines to the inch (570 lines to the mm). The photographs have all been made in the second order, which gives a linear scale of about 1 mm = 1.5 Å. The spectrograph has been used in conjunction with the Snow telescope, the concave mirror of which forms a solar image about 6.7 inches (17.0 cm) in diameter on the slit. During the exposure of the photographic plate to the spectrum of the spot the light from the photosphere is excluded from the slit, but at the conclusion of this exposure the ordinary solar spectrum is photographed on either side for purposes of comparison. This is readily done by means of an occulting bar which moves across the slit and has an opening of variable size which may be adjusted to the size of the spot under observation. The exposures are timed to give as nearly as possible the same intensity to the continuous spectrum of the spot and of the comparison spectrum. The ratio of the two exposures varies, of course, with the definition of the solar image, the transparency of the sky, and the size and blackness of the spot, as well as the wave-length of the region photographed. Under average conditions at λ 5500 the spot requires about six times as long as the comparison spectrum, while at λ 4000 this ratio increases to about ten or eleven.

The present paper contains a list of the lines affected in sun-spots for the region λ 4000 to λ 4500. It will be followed by other lists giving

which is the spark line, and it is decidedly weakened in spots; the former, on the other hand, is strengthened, and unless the dispersion of the instrument is sufficient to separate the two lines, it might well appear that the blend is not affected. The third line, λ 5188.87, seems to be distinctly weakened on our plates. The fourth and fifth lines, λ 5502.9 and λ 5621.7, either are not represented in the solar spectrum, or the lines are so faint (not above 000 on Rowland's scale) that conclusions can hardly be drawn as to their behavior.

the results obtained by one or both of us in other parts of the spectrum. Our series of photographs in the ultra-violet may not be completed for some time, and for this reason the present list begins at λ 4000.

The tables are of the same general character as those given by us in previous publications. The intensities are based upon Rowland's scale, and in the few instances in which his values for individual lines seem to need modification notes to this effect are added in the margin. For purposes of identification we have compared our list with the tables of the wave-lengths of arc lines by Hasselberg, and the "enhanced" line tables of Lockyer, the wave-lengths given in the marginal notes being from these sources. In general, only the more obvious identifications are included, and no attempt has been made to present alternative identifications unless they seem to be of special significance as regards the behavior of the lines in the spot spectrum. An extended discussion of this sort belongs rather to a detailed analysis of the results than to the catalogue proper, and we shall hope to enter into this subject farther in a concluding paper.

George E. Hale
Walter S. Adams

The following is a list of the negatives employed in obtaining the results given in this paper. All of the plates were secured by Mr. Ellerman except L 128, which was taken by the writer.

TABLE I

Plate	Date	Greenwich Spot Number
L 76	1906, June 29	5898
L 77	June 30	5898
L 88	July 2	5898
L 82	July 2	5898
L 83	July 2	5898
L 84	July 2	5898
L 92	July 9	5898
L 94	July 30	5944
L 95	July 31	5944
L 101	Aug. 2	5944
L 128	1907, June 22	6205
L 134	July 19	....

In the case of plate L 134 the Greenwich spot number has not as yet been published.

TABLE II

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4000.61	*Fe*	2	2–3	3	
4001.32	*Mn*, —	3	2	4	
4003.08	—	2	1–2	6	
4003.91	*Ce–Fe–Ti*	3	3–4	3	Widened
4005.86	*V*	3	2–3	3	Spark line of *V*
4006.90	—	2	2–3	3	
06.98	—	1			
4009.02	—	2	6	7	
09.08	*Ti*	3			
4009.29	—	1	0–1	3	
4009.81	*Ti*	1	5–6	3	Much widened
09.86	*Fe*	3			
4010.33	*Ce–Fe*	1	1–2	3	
4010.74	—	3	2–3	3	Rowland's intensity too high: 2 better
4011.56	*Fe*	3	3–4	3	
4012.54	*Ti*, *Ce*	4	3–4	6	Narrow. Spark lines of *Ti* and *Cr*
12.63	*Cr*	0			
4013.80	*Ti–Fe*	3	3–4	3	
4015.53	—	0	0–1	3	Hasselberg gives *Ti* 4015.56
4015.76	—	3	2	3	Narrow. Spark line of *Ni*
4017.93	*Ti*	0	0–1	3	
4018.23	*Mn*	3	9	4	Widened
18.27	*Mn*	4			
4019.20	*Ni–Ce*	1	1–2	3	Widened
4019.45	*Co*	0	0–1	7	Rowland's intensity too high: 00 better
4020.34	—	1	2	3	
20.42	—	2			
4020.55	*Sc*	1	3	8	
20.64	*Fe*	1			
4021.06	*Nd–Co*	3	3–4	8	
4022.02	*Ti–Fe–V*	5 d?	6	3	
4022.37	*Fe*	1	1–2	4	
4023.53	*V*, *Co*	3	2–3	8	Spark line of *Co*
4023.83	*Sc*	2	3	7	
4024.73	*Ti*	3	4	3	
4025.16	*Cr*	0	4	7	Widened to violet. Spark line of *Ti*
25.29	*Ti–Ce*	3			
4026.32	*Cr*	0	1	8	
4026.58	*Mn*	2 N	4	3	
26.69	*Ti*	1			
4027.19	*Co*	1	3	8	
27.25	*Cr*	0			
4027.82	—	1	0–1	7	
4028.50	*Ti–Ce*	4	3	8	Spark line of *Ti*
4030.34	*Fe*	2	2–3	3	
4030.65	*Nd–Fe–Ti*	5	5–6	3	
4030.88, 30.95	*Mn*	10 d?	11	4	
4033.22	*Mn*	8 d?	10	3	Widened
33.34	*Fe?*	1			

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4034.64	*Mn*	6 d	8	3	Widened, hazy
4036.52	—	0	0–1	8	
4036.92	*V*, —	1	0–1	7	
4037.27	—	2	2	8	Very hazy. Rowland's intensity
4038.94	—	2	2–3	3	[too high: 1 better
4040.09	*Fe*	1	1–2	3	
4040.24	*Fe?*	2	1–2	3	
4040.79	*Fe*	3	4	4	Hazy. Rowland's intensity too
4041.43	*Fe*	3	9	5	Widened [high: 2 better
41.52	*Mn*	5			
4044.06	*Fe*	3	4	6	
44.14	—	2			
4045.54	*Co*	5	5–6	3	Difficult: in shade of following line
4045.98	*Fe*	30	32	6	Probably slightly strengthened
4047.82	*Y*	0 N	1–2	7	
47.96	—	0 N			
4048.82	*Zr*	1	7	6	Widened
48.91	*Mn–Cr*	5			
4050.83	*Fe*	2	1–2	3	
4051.49	*Cr–V*	0 Nd?	0–1	3	
4052.60	*Mn, Fe*	2	4	3	Rowland's intensity too high: 4 better for total
52.65	—	3			
4053.98	*Cr–Fe–Ti*	3	2–3	7	
4054.59	*Zn*	0	1–2	3	Strengthened to red
54.71	*Sc*	00 N			
4054.96	*Fe*	2	4	6	
55.02	*Fe*	3			
4055.70	*Mn*	6	7	6	
4056.50	*Fe*	1	2	3	
56.60	—	0			
4057.37	*Co*	1 N	4–5	4	Not fully separated from following line
57.50	*Fe*	3			
4057.67	—	7	5	4	
4059.08	*Mn*	3	4	6	
4059.54	*Mn*	1 Nd?	2	3	Widened to red
59.65	—	0			
4059.87	*Fe*	2	1–2	7	
4060.42	*Ti*	1	2	8	
4060.64	—	0	00	3	Nearly obliterated
4060.92	—	0	0–1	3	
4061.78	*Mn*	2 Nd	2–3	6	Fringe on violet side
4062.10	—	2	1–2	3	
4062.60	*Fe*	5	5–6	5	Widened
4064.36	*Ti*	1	2	5	
4065.24	*Mn–Ti*	2 d?	3	7	
4066.52	*Co*	2	3	7	
4067.14	*Cr–Fe*	5	5–6	3	
4067.43	*Fe*	3	4–5	6	
4068.14	*Fe–Mn*	6	7	6	Very hazy, widened
4068.69	*Co*	0	0–1	3	
4070.43	*Mn*	3	4–5	7	Much widened

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4073.92	*Ce, Fe*	4	5	4	
4075.26	— *Nd*	2 N	1–2	6	Rowland's intensity too high: 1 better
4076.10	*Fe*	3	2–3	7	
4077.88	*Sr*	8	8	6	Winged
4078.52	*Zr–Fe*	4	8	7	
78.63	*Ti*	3			
4079.34	*Fe*	2	6	4	Widened
79.39	*Mn*	3			
4079.57	*Mn*	3	3–4	3	
4080.00	*Fe*	3	4	7	
4080.37	*Fe, Nd, Cr*	3	3–4	3	
4081.38	*Zr, Ce*	0	2	4	
81.42	—	1			
4082.26	*Fe*	2	2–3	3	
4082.59	*Sc–Fe–Ti*	3	4	8	
4083.10	*V–Mn*	4	5	7	Widened
4083.72	*Fe*	2	7	4	
83.78	*Mn, Y*	4			
4084.65	*Fe*	5	5	7	Perhaps winged
4085.47	*Fe*	4	5–6	7	Widened
4086.47	*Co*—	3 d?	4	7	Much widened
4086.86	*La*	1	1–2	3	
4089.37	*Fe*	3	4	6	
4090.73	*V*	1	2	8	
4091.11	*Ce* —	3	3–4	4	
4091.71	*Fe*	3	3–4	6	
4092.82	*V, Ca*	3 d?	4–5	8	
4095.09	*Ca?*	4	5	8	
4095.42	*Mn*	0	0	6	
95.51	—	0			
4095.63	*V*	0	1	6	
4096.37	—	1	1–2	6	
4097.24	*Fe*	3	3	7	Very broad and hazy
4097.61	—	000	0	3	
4097.81	—	0	0–1	6	
4098.12	—	0	0–1	3	Seen as fringe on following line
4098.34	*Fe*	5	4–5	6	
4098.69	—	4	7	7	
98.75	—, *Co?*	2			
4099.21	—	0	1–2	6	Very broad
99.33	*Ti*	00			
4099.94	*V*	2	4	8	
4100.32	*Fe*	2	1–2	6	
4100.50	—	0	1	3	
4100.90	*Fe*	4	4–5	5	
4102.00	*H, In*	40 N	20	7	$H\delta$ is both narrowed and weakened
4102.32	*V*	0	1	7	
4103.10	*Si, Mn*	5	6	4	
4104.91	*Co, V*	00	0	7	
4105.32	*V*	2	4	8	Broad
4105.98	—	000	00	3	

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4106.42	*Fe*	2	3–4	7	
4106.58	*Fe*	2	1–2	6	
4106.8			0	3	Perhaps a blend of two faint solar lines
4107.65	*Ce–Fe*	5	6	4	Widened, hazy
4108.29	—	1	1–2	4	
4108.69	—	2	3	7	
4109.22	*Fe*	3	3–4	5	Narrow
4109.90	*V*	2	7	7	Much widened
09.95	*Fe*	3			
4111.15	—	1	00	3	Nearly obliterated
4111.51	*Ce?*	1	1–2	4	
4111.94	*V*	4	6	8	Very broad
4112.48	*Fe*	2	3	7	Much widened
4112.87	*Ti*	1	2	8	
4113.07	—	1	3	8	Narrow
13.12	*Fe*	3			
4113.68	—	000 Nd?	1	7	Broad patch
4114.27	—	00 d	0–1	3	
4114.61	*Fe*	4	5	6	Widened
4115.33	*V*	3	4–5	8	
4116.63	*V*	1	3–4	8	
16.71	*V, Fe?*	0			
4116.97	*Nd?*	00	0	3	Seen as fringe on 4116.86
4117.11	—	0	0–1	3	
4117.59	—	000	0–1	3	Broad patch
4118.01	—	2	3	7	Widened
4118.31	*V*	0	0–1	7	
4118.71	*Fe*	5	6	5	
4118.93	*Co*	4	7	5	
19.05	*Fe*	2			
4120.78	—	0	1	3	Broad patch. Hasselberg gives *V* [4120.69
4121.48	*Cr–Co*	6 d?	7	5	
4121.96	*Fe, Cr*	3	3–4	5	
4122.82	—	1	1–2	3	
4123.38	*La*	1	0	5	
4123.54	*Cr*	0	3–4	8	
23.66	*Ce, V–Mn*	1			
23.71	*Ti*	000			
4123.91	*Fe*	5	4	4	Rowland's intensity too high: 4 better
4124.64	—	0	0–1	3	
4125.53	—	000	0	3	
4125.78	*Fe*	3	3	5	Narrow
25.85	—	1			
4126.20	—	000	5	5	
26.34	*V–Fe*	4			
4126.67	*Cr*	2	3	7	Rowland's intensity too high: 1 better
4127.01	—	1	2	7	
27.07	*Cr*	00			
4128.25	*Ce–V*, —	6 d	8	6	

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4128.46	—	00	0	3	
4128.89	—	2	0	7	Nearly obliterated; fringe on red side probably due to 4129.13
4129.34	*Ce* —	3	3–4	6	
4129.62	—	2	1–2	7	
4130.11	—	0	3	7	
30.20	*Fe*	2			
4130.60	—	0	3	6	
30.80	*Ba*	2			
4131.27	*Ce, Mn*	1	2	4	Hasselberg gives *V* 4131.32
4131.51	*Cr*	0	1	7	
4132.10	*V*	2	14	6	Widened to violet
32.24	*Fe–Co*	10			
4132.69	—	3	2	7	
4133.06	*Fe*	4	4–5	5	
4133.76	*Fe*	2	0	7	Rowland's intensity too high: 1 better. Fringe to violet
4134.49	*Fe?*	3	7–8	6	
34.59	*Fe?*	3			
4135.84	—	00	1–2	7	
35.92	*Zr*	0			
4136.68	*Fe*	4	5	7	
4137.16	*Fe*	6	7	4	Spark line of *Mn* falls here
4137.43	*Ti, Mn*	0 Nd?	3–4	7	Widened to violet
37.57	—	2			
4138.13	—	0	0–1	3	Broad
4138.52	—	0 N	6	8	
4139.52	—	00	1	4	Broad patch. Hasselberg gives *V* 4139.39
39.61	—	000			
4140.09	*Fe*	6	6–7	3	
4140.56	—, *Fe?*	3	3–4	7	Much widened, perhaps winged
4140.91	—	0	0–1	3	
4142.02	*Fe*	4	4–5	3	Widened
4143.57	*Fe*	4	5–6	5	Narrowed in spot
43.66	—, *Mo*	2			
4144.04	*Fe*	15	13	6	Narrowed in spot
4146.22	*Fe*	3	3	6	Fringe on red side
4146.84	—	0 N	1	7	Broad
4147.14	—	2	1	7	
4147.50	—	2	1–2	3	Rowland's intensity too high: 1 [better
4147.84	*Fe*	4	6–7	7	
4148.55	—	00	0	3	
4149.53	*Fe*	4	5	6	Widened
4149.92	—	2	3	7	
4150.41	—	4	4–5	7	Rowland's intensity too high: 3 [better
4150.61	*Co*	1	0	7	
4151.13	*Ce–Zr, Ti*	1	1–2	6	
4152.24	—	1	4–5	5	
52.34	*Fe*	3			
4152.69	*C?*	00	0–1	3	Hasselberg gives *V* 4152.81
52.76	*Zr*	00			
4152.93	*Cr, La*	0	00–0	3	

TALBE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4153.22	*Cr*	00	0–1	7	
4153.78	*Co*	0	0–1	3	
4153.97	*Cr*	1	6	6	
54.07	*Fe*	4			
4154.67	*Fe*	4	4–5	7	Widened
4154.98	*Fe*	4	4–5	5	
4155.21	—	00	0	2	
4155.68	—	00	1	3	Broad patch
55.80	—	00			
4156.07	—	1	0–1	3	
4156.39	*Zr*	1	2	4	
56.47	—	3			
4157.95	*Fe*	5	5–6	3	
4158.54	*C?*	0	1	7	
58.59	*C?*	00			
4159.35	—	5	4	7	
4159.80	*Ti*	0	1	4	
4160.53	—	2	3	7	Widened. Hasselberg gives *V* 4160.57
4161.37	*Zr* —	2	1–2	3	
4161.68	—	4	3–4	7	Widened. Spark line of *Ti* falls here
4161.96	*Sr*	1	00	7	Nearly obliterated. Spark line of *Sr*
4162.28	—	00 N	0	3	
4162.62	*C*, —	1 N	0–1	3	
4162.82	*Ce*, *C*	1 N	0–1	3	
4163.07	—	00	1	6	
63.14	—	000			
4163.64	—	0 d	0–1	3	
4163.82	*Cr–Ti*, —	4	3–4	4	Spark line of *Ti*
4164.80	—	0	2	7	Hasselberg gives *Ti* 4164.80
64.94	—	0			
4165.28	—	0	1	7	
4165.55	*C*, *Fe*	3 d	2–3	3	Narrow
4165.76	—, *Ce*	1	0–1	7	
4166.16	*Ba*	0	1–2	6	
66.26	—	00			
4166.36	—	00	2	6	Hasselberg gives *Ti* 4166.45
66.46	—	0			
4167.44	—	8	6	6	
4168.02	*Ce–Fe*	2	4–5	6	
68.13	*Ni*, *C*	2			
4168.63	—	00 N	3	7	Strengthening due to 4168.63
68.78	—	2			
4169.11	—	2	2–3	3	
4169.93	—	2	2–3	3	
4171.07	*Fe*	4	4–5	3	
4171.85	*C*, *Fe?*	2	2–3	6	
4172.07	*Ti*, *Fe*	2	1–2	6	Spark line of *Ti*
4172.21	*Al*	1	4–5	7	
72.30	*Fe–Ce*	2			

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4172.80	—	2	6	5	Weakened to violet, probably strengthened to red
72.92	*Fe*	4			
4173.14	—	1	0–1	6	
4173.62	—	3	4–5	7	Spark line of *Fe*
73.71	—	3			Spark line of *Ti*
4174.10	*Fe*	3	4	6	Weak to red. Spark line of *Ti* at 4174.20. Hasselberg gives *V* 4174.18
74.24	—	0			
4174.97	*Cr*	0	5–6	7	
75.08	*Fe*	4			
4175.29	—	1 N	0	7	
4175.81	*Fe*	5	5–6	3	
4178.22	—	2	1	7	
4179.02	—	3	2	7	Spark line of *Fe*
4179.54	*V*, —	3 d?	3–4	7	Widened
4180.56	—	1	1–2	6	
4181.35	—	0	0–1	3	
4181.92	*Fe*	5	5–6	4	
4182.14	—	2	1–2	7	Narrow
4182.92	—	2	1–2	4	Narrow
4183.17	—	1	0–1	5	
4183.48	*Zr*	1 N	2	7	Weak to red. Spark line of *V* at 4183.60
83.62	—	2 N			
4184.16	—	4	3	7	Rowland's intensity too high: 3 better
4184.47	—	2	1–2	7	Narrow. Spark line of *Ti* at 4184.40
4185.06	*Fe, Cr*	4	5–6	7	
4186.28	*Ti*	1	2	7	
4186.78	*Ce–Zr*	2 N	1–2	6	
4187.20	*Fe*	6	7	6	
4187.94	*Fe*	5	9	6	
88.02	—	3			
4188.89	—	4	3–4	5	
4189.14	*C*, —	1	2–3	4	
89.26	—	1			
4189.98	*V*	0 Nd?	1	7	Rowland's intensity too high: 00 better
4190.29	*Cr*	0 N	1–2	6	
90.40	*C*	0			
4190.87	*C, Co*	1 Nd?	2–3	8	
4191.60	*Fe*	6	7–8	7	Winged
4191.84	*Fe*	3	3–4	6	
4192.56	*C*	00 N	00–0	3	
4192.73	—	2 N	1	7	
4194.89	*C*, —	1	3	6	Very broad
95.01	*Cr*	1			
4195.49	*Fe*	5	5–6	6	
4195.68	—	1	3–4	7	
95.78	*Fe–C*	2			
4197.26	*C*	2	3	7	Widened to red
97.39	*Cr*	0			

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4197.81	—	00	1	6	Hasselberg gives *V* 4197.77
97.90	—	00			
4198.22	*Fe*	2	2–3	4	
4198.40	—	4	7	4	
98.49	*Fe*	4			
4198.80	*Fe*	3	3–4	6	
4199.27	*Zr–Fe*	5	6	4	Very hazy
4200.04	—	1 N	4	7	
00.15	*Fe*	2			
00.26	*Cr*	00			
4200.95	*Ti*	1	2	7	
4201.09	*Fe*	3	3–4	4	
4202.20	*Fe*	8	10	6	Winged
4203.62	*Ti*	00 N	3–4	7	
03.73	*Cr*	2			
4204.88	—	1	2	5	
04.92	—	2			
4205.19	—	1	2	7	Widened
05.24	—	1			
4205.70	—	2	2–3	5	
4206.74	—	1	5	6	Rowland's intensity too low: 5 better for total
06.86	*Fe*	3			
4207.29	*Fe*	3	3–4	7	
4208.77	*Fe*	3	3–4	7	
4209.98	*V*	1	2	7	
4210.49	*Fe*	4	8–9	6	Widened
10.56	—	3			
4211.13	—	3 N	2–3	3	
4211.51	*C–Cr*	0 N	0–1	4	
4211.90	*Mn*, *C*	0	1	6	Hasselberg gives *Ti* 4211.85
4212.05	*Zr–*	2	1	7	
4213.81	*Fe*	3	3–4	7	Narrow
4215.58	*Fe*	2	8	3	Spark line of *Sr*
15.70	*Sr*	5 d?			
4216.35	*Fe*	3 d?	4–5	7	Widened
4216.76	—	1 N	0–1	3	
4217.72	*La*, *Fe–Cr*	5 d?	5–6	3	
4218.56	— *Zr*	1 Nd	1–2	6	
4220.51	*Fe*	3	4	6	
4221.63	—	1 N	1	4	
21.74	*Cr*	0			
4222.38	*Fe*	5	6	6	
4223.64	—	1	1–2	3	
23.74	—	1			
4224.34	*Fe*	4	5	3	Hasselberg gives *V* 4224.30
4224.67	*Cr–Fe*	3	4	7	
24.79	*Ti*	00			
4225.02	—	2 N	1–2	7	Spark line of *Cr*
4225.62	*Fe*	3	3–4	5	
4226.90	*Ca*	20 d?	25	8	Very difficult line. Widened and winged
4228.10	—	1 N	0–1	3	

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4229.68	*Fe*	2	2–3	3	Widened to violet
4229.93	*Fe*	3	4	4	Difficult
4232.76	*V*	∞	3–4	9	
32.89	*Fe*	2			
4233.33	*Mn*	4	3	8	Strong spark line of *Fe* falls here
4133.77	*Fe*	6	7	7	
4234.17	*Co, V*	0 N	0–1	8	Rowland's intensity too high: ∞ better
4234.71	*Zr*	0 N	1	8	Hasselberg gives *V* 4234.70
4235.30	*Mn*	2	6	4	
35.45	*Mn*	3			
4238.19	*Fe*	3	3–4	8	Widened
4239.52	—	2	2–3	8	
4239.89	*Fe, Mn*	3			
40.01	*Fe*	3	9	5	
40.12	—	1			
4240.54	*Fe*	2	4	8	Hasselberg gives *V* 4240.53
40.62	—	1			
4240.87	*Cr*	1	1–2	3	
4241.28	*Fe–Zr*	2	3	8	
4241.68	—	∞ N	1	8	Broad patch
41.87	—	∞ N			
4242.32	—	0	1	4	
4242.54	—	2	3	8	Spark line of *Cr* at 4242.54
42.62	—	2			
4243.98	—	2	1–2	3	Narrow
4245.42	*Fe*	4	8	7	Probably winged
45.52	—	2			
4247.00	*Sc*	5	6	5	
4247.46	—	1	6	4	Hasselberg gives *V* 4247.46
47.59	*Fe*	4			
4247.73	—	0	∞	8	
4248.48	*Ti*	∞	2	8	Widened to violet
48.58	—	1			
4249.10	—	2 N	1–2	8	
4250.29	*Fe*	8	9	5	
4252.39	—	∞	1–2	9	
52.47	*Co*	0			Broad
4252.78	—	0 N	1	5	Weak to violet. Spark line of *Cr* at 4252.80
52.92	—	1 N			
4253.16	—	1	0–1	8	Spark line of *Mn*
4253.36	—	1	1–2	3	
4254.50	*Cr*	8	10	7	Widened: probably winged
4255.66	*Fe, Cr*	1	2–3	5	
55.79	—	1 N			
4256.29	*Ti*	0	2–3	4	Very broad
56.37	—	1			
4257.82	*Mn*	2	2–3	6	
4258.32	—	1 N	0–1	3	
4258.48	*Fe*	2	4	9	
4259.46	—	1 Nd?	2	3	Hasselberg gives *V* 4259.46
4260.64	*Fe*	10	9	4	Apparently narrowed in spot

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4261.68	—*Cr*	2	3	7	Widened to red
61.75	*Ti*	oo			
4262.09	—	1	0–1	8	Spark line of *Cr* at 4262.15
62.14	—	1			
4263.29	*Ti, Cr*	2	3	8	
4264.37	*Fe*	3	4	4	
4264.90	*Fe*	2	1–2	3	
4265.83	*Ti*	0	0–1	8	
4266.08	*Mn*	2	2–3	8	
4266.78	—	0	0–1	3	Rowland's intensity too high: oo better
4267.12	*Fe*	3	3–4	7	
4268.78	—	0	3–4	7	Hasselberg gives *V* 4268.78
68.92	*Fe*	2			
4269.45	—	0	000	3	Nearly obliterated. Perhaps spark line of *Cr*
4269.90	—	2	3	8	
70.02	—	2 N			
4271.93	*Fe*	15	15	7	Very hazy. Probably narrowed in spot
4272.70	*Ti*, —	1	2	8	
4274.75	*Ti*	2	12	8	Much widened to violet
74.96	*Cr*	7 d?			
4277.15	*V*, —	1 N	1–2	6	
4277.69	—	2 d?	3	8	Much widened
4278.39	*Fe-Ti*	3	3–4	6	Narrow
4279.01	*Ti*, —	1 N	1–2	7	
4279.87	—	2 Nd?	1	3	
4280.56	*Cr*	1	2	8	Broad
4280.94	—	1	0–1	3	
4281.26	*Mn*	2	2–3	6	Narrow
4281.53	*Ti*	0	1–2	8	
4282.13	—	2 N	1–2	3	
4282.56	*Fe*	5	6	3	
4282.86	*Ti*	0	0–1	8	
4283.17	*Ca*	4	5–6	9	
4283.90	—	000	0	3	
4284.22	*Mn, V*	0	0–1	3	Seen as fringe on following line
4284.38	—	2 Nd?	1	9	Spark line of *Cr*
4284.99	—	1	0–1	3	Rowland's intensity too high: 0 better
4285.16	*Ti*, —	2	2–3	8	
4285.52	—	1			
85.60	*Fe*	3	3–4	4	
85.69	—	1			
4286.17	*Ti*, —	2	3–4	8	Narrow
4287.57	*Ti*	1	2	8	
4288.31	*Ti, Fe*	1	2	4	
4288.89	—	(oo N)	1	3	Evident error in Rowland's intensity. Map shows strong line here. Spot intensity is on basis of 2 in Sun

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4289.12	—	1	4–5	8	
89.24	*Ti*	2			
4289.52	*Ca*	4	5	8	
4289.88	*Cr*	5	8	8	*Ti* line probably weakened.
90.08	*Ti*	1			
4290.38	*Ti*	2	1–2	6	Narrow. Spark line of *Ti*
4291.11	*Ti*	3	3–4	8	
4291.28	*Ti*	2	2–3	3	
91.38	—	1			
4291.63	*Fe*	2	3–4	8	Widened
4292.14	*Cr, V*	0	0–1	8	Difficult. Seen as fringe on following line
4292.21	—	1	2	5	Spark line of *Mn* at 4292.35
92.29	—	2			
4292.45	—	2	2–3	7	
4293–19	—	2	4	8	
93.27	—	3			
4294.20	*Ti*	2	9	8	Spark line of *Ti*
94.30	*Fe*	5			
4295.19	—	3 d?	4–5	8	
95.38	—	3 Nd?			
4295.91	*Cr, Ti*	2	3–4	8	Narrow
4296.74	—	3	3	5	Spark line of *Fe* at 4296.72
96.84	*Zr?*	1			
4297.37	—	2	3	5	
97.45	—	2			
4297.68	—	1 N	0–1	5	
4297.91	*Cr, V*	0	0–1	8	
4298.14	*Ti*	1	4	8	
98.20	*Fe*	2			
4298.36	—	1	0–1	3	
4298.83	*Ti*	2	3	8	
4298.97	—	2	1	3	
4299.15	*Ca*	3	4	9	
4299.41	*Ti, Fe*	4	5	3	
4299.80	*Fe, Ti*	2	3	9	
4299.99	—	1 N	0–1	3	
4300.21	*Ti*	3	2–3	9	Spark line of *Ti*. Rowland's intensity too low: 4 better
4300.48	—	1 N	0–1	3	
4300.73	*Ti*	2	3	8	
4300.99	—	1	0–1	7	
4301.16	*Ti*	2	8	8	Weak on red edge; *Ti* line strengthened
01.26	—	4			
01.33	—	1			
4301.90	—	0 Nd?	00–0	3	
4302.08	*Ti*	2	1–2	4	Spark line of *Ti*
4302.69	*Ca*	4	6	9	Probably winged
4303.34	—	2	1	8	Spark line of *Fe*
4303.58	—	1 N	0–1	3	
4303.99	—	2	4	8	
04.10	—	4			

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4304.42	—	1	0–1	3	
4304.55	—	1	0–1	3	
4304.73	*Fe*, —	2	1–2	6	
4305.27	—	1	0–1	7	
4305.48	—	1	3–4	5	Spark line of *Sr*
05.61	*Fe*, *Sr*, *Ti*, *Cr*	3			
4306.08	*Ti*	4	5–6	8	
4306.86	—	2	3	8	
07.02	—	2			
4307.91	*Ca*	3	10	8	Violet component probably strengthened, red weakened. Spark line of *Ti* at 4308.10
08.08	*Fe*.	6			
4309.06	—	1	2–3	7	
09.20	*Fe*	2			
4309.54	*Fe*	3	3–4	7	
4309.79	—	1	1	5	
09.88	—	1			
4309.99	—	0	1–2	7	Hasselberg gives *V* 4309.95
10.07	—	0			
4310.27	—	2	1	7	
4310.54	—	2	2–3	4	
10.63	—	1			
4310.86	—	2 N	2–3	6	
4311.06	—	1	1–2	6	
11.15	—	1			
4311.61	—	2	2–3	5	Spark line of *Mo* at 4311.71
11.67	—	2			
4312.25	—	2	2	4	
12.31	—	1			
4313.03	*Ti*	3	2–3	7	Spark line of *Ti*
4213.80	—	2 Nd?	1–2	3	
4314.25	*Sc*	3	3–4	7	
4314.96	*Ti*	1	2–3	8	
4315.14	*Ti*	3	8	6	Spark line of *Ti*
15.26	*Fe*	4			
4316.96	*Ti*?	1	0–1	8	Spark line of *Ti*
4318.82	*Ca*, *Mn*?	4	6	8	Winged. Hasselberg gives *Ti* 4318.83
4320.66	—	0	1–2	7	
20.76	—	00			
4321.12	—	2	1–2	7	Possibly spark line of *Ti*
4321.81	*Ti*	0	1	8	
4323.39	—	2 Nd?	1	5	
4324.01	—	3	2	5	
4324.57	—	2 N	1–2	4	
4325.15	*Sc*	4	6	7	Widened to red
25.31	*Ti*, *Cr*	1			
4325.94	*Fe*	8	8	6	Apparently narrowed in spot
4326.52	*Ti*	0	1	7	Narrow
4327.27	*Fe*	3	2–3	3	
4328.08	*Fe*	2	2–3	6	Much widened: very hazy
4328.77	—	0 N	00–0	8	

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4329.45	—	0 N	0	3	
29.56	—	0 N			
4330.19	*V*	0 N	2	9	
4330.40	—	1	0	7	
4330.57	—	0	00–0	3	Spark line of *Ti* at 4330.50
30.61	—	0			
4330.87	*Ti, Ni*	2	1–2	8	Spark line of *Ti*
4331.81	*Ni*	2	2	7	Very narrow line in spot. Measures show no change
4332.99	*V*	0	2	9	
33.08	—	0			
4335.10	*La*	0	1	7	Broad. Hasselberg gives *Ti* 4334.98
4337.22	*Fe*	5	7	8	Winged
4337.72	*Cr*	3	4–5	8	
4338.08	*Ti*	4	3	9	Spark line of *Ti*
4338.43	*Fe*	1	2	9	
4339.62	*Cr*	4	6	8	
4339.88	*Cr*	3	4	8	
4340.30	*Cr*	0	0–1	7	
4340.63	*H*	20 N	8	8	$H\gamma$ is both weakened and narrowed
4341.17	*V*	0	2	9	
4341.53	*Ti?*	2	1	8	Spark line of *Ti*
4342.35	—	0	1	3	Broad patch
42.48	—	00			
4343.37	*Cr*	2	4–5	7	
43.43	*Fe*	2			
4343.86	*Fe*	2	2–3	3	
4344.13	—	1 N	0	3	Rowland's intensity too high: 0 better. Spark line of *Mn*
4344.45	*Ti*, —	2	1–2	7	Spark line of *Ti*
4344.67	*Cr*	4	6	8	
4345.05	—	0	00	3	
4345.25	—	00	0–1	3	Broad patch
45.40	—	0000			
4346.28	—	00	00–0	3	Hasselberg gives *Ti* 4346.26
4346.45	—	1	0–1	9	
4346.99	*Cr*	1	1–2	9	Rowland's intensity too high: 0 better
4347.40	*Fe*	1	2	9	
4348.50	—	1 N	0–1	7	
4349.11	*Fe*	2	2–3	3	
4351.00	*Ti*	1	0–1	9	Spark line of *Ti*
4351.22	*Cr*	3	5	8	
4351.93	*Cr*	5	11	7	Strengthening very doubtful. Spark line of *Fe* at 4351.93
52.08	*Mg*	5 Nd?			
4352.91	*Fe*	4	7	9	Widened to red
53.04	*V*	0			
4355.26	*Ca?*	2	3	9	Perhaps winged
4356.06	—	0	2	9	Strengthening due mainly to violet component. Hasselberg gives *V* 4356.10
56.16	*Ni*	0			

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4356.53	—	0	00	4	
4356.77	—	0	0–1	6	Widened to red
4359.65	*Ni*	0			
59.78	*Cr*	3	5	4	Spark line of *Zr*
59.91	*Zr*	0			
4360.45	—	1	0–1	4	
4360.64	*Ti*	1	1–2	7	
4362.91	—	0 N	00	3	
4363.27	*Cr*	1 N	1–2	4	
4363.46	—	0 N	00–0	4	Rowland's intensity too low: 1 better
4363.63	—	0	1–2	8	Very broad. Hasselberg gives *V* 4363.69
63.77	—	0			
4365.17	—	000	00	3	
4366.06	*Fe*	2	2–3	3	
4367.22	—	000	0	3	Hasselberg gives *V* 4367.24
4367.75	*Fe*	5	6	8	Weak at red edge. Spark line of *Ti*
67.84	*Ti*	2			
4368.07	*Fe*	2	2–3	7	Narrow
4368.22	—	00	0	3	Hasselberg gives *V* 4368.25
4369.05	*Ti*	00 Nd?	0	3	
4369.57	—	1	0	6	
4371.14	*Zr*	1	1–2	7	Spark line of *Zr*
71.22	—	1			
4371.44	*Cr*	2	3–4	7	
4372.50	—	0 d?	0–1	7	Very broad. Hasselberg gives *Ti* 4372.54
4372.90	—	0	0	6	
73.01	—	0			
4373.42	*Cr*	1	2–3	7	Hasselberg gives *V* 4373.40
4373.73	*Fe*	2	1–2	5	Narrow
4374.98	*Zr*	0	3–4	4	
75.10	*V, Mn*	2			
4375.73	—	0	0	5	
75.82	—	0			
4376.11	*Fe*	6	8	6	Probably winged
4377.39	—	2 N	1–2	6	
77.53	—	0 d?			
4378.42	—	2 Nd?	1–2	5	
4379.40	*V*	4	7	6	Very broad
4380.32	*Co*	2 Nd?	1	6	
4380.88	—	2 Nd?	1	5	Broad
4381.27	*Cr*	0	0–1	5	Hazy, broad
4382.85	*Mn*	0	1–2	6	
82.93	—, *Fe*	2			
4384.48	—	1	0	4	
4384.87	*V*	3	4–5	6	Much widened
4385.14	*Cr*	2	3	6	
4385.55	—	2	0–1	5	Spark line of *Fe*
4387.01	*Ti?*	1	0	7	Spark line of *Ti*
4387.22	—	1 N	0	6	Possibly spark line of *Pb*
4388.06	*Fe, Co*	2	2–3	4	Widened

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4388.89	—	0	0	3	
89.03	—	0 N			
4389.41	*Fe*, —	2	3	6	
4390.15	*V*	2	4	7	
4391.12	*Fe*	2	2–3	3	Weak on red edge. Spark line of *Ti*
91.19	*Ti*	1			
4391.82	*Co*	0	3	7	Weak on violet edge
91.92	*Cr*	1			
92.03	*Co*	0			
4392.24	*V?*	1 N	1–2	7	
4393.44	—	0	1	7	
4393.69	—	1 Nd?	0	5	
4393.97	*V?*	0	1–2	6	
94.09	*Ti*	0			
4394.22	*Ti?*	2	1–2	5	Narrow
4394.94	—	00	0–1	3	Hasselberg gives *V* 4394.98
95.02	*Zr*	00			
4395.20	*Ti*	3	2–3	7	Narrow. Spark line of *Ti*
4395.41	*V*, *Zr*	2	3	7	
4396.01	*Ti*	1	0–1	6	Spark line of *Ti*
4397.12	—	1 N	0–1	4	
4399.94	*Ti*, *Cr*	3	2–3	6	Spark line of *Ti*
4400.56	*Sc*	3	3–4	6	
4400.74	*V*	1	3	7	
4401.18	—	1 N	0–1	4	Possibly spark line of *Pb*
4403.35	—	1	0–1	6	
4404.43	*Ti*	1 N	1–2	4	
4404.93	*Fe*	10	9	6	Apparently narrowed in spot
4406.81	*V*, —	2	4	7	
4407.81	*V*	2	8	7	
07.87	*Fe*	4			
4408.36	*V*	2	3–4	7	
4408.58	*Fe*	3	7	7	Very broad
08.68	*V*	2			
4409.41	—	0	00	5	Widened to red
4409.68	—	1	0–1	4	
4410.68	*Ni*	2	1–2	3	
4411.24	*Cr* —	1	1–2	3	Widened. Spark line of *Ti* falls here.
4412.09	—	1	0	6	
4412.30	*V*	00	2	6	Hazy
12.42	*Cr*	0			
4413.76	—	1	0	6	
4415.29	*Fe*	8	7	4	Apparently narrowed in spot
4415.72	—	3	2–3	6	Narrow
4416.64	*V*	0	2–3	7	
4416.98	—	2	1	6	Narrow
4417.45	*Ti*	0	1–2	7	Broad
17.58	*Co*	00			
4417.88	*Ti*, —	3	2–3	6	Spark line of *Ti*
4418.50	*Ti*, —	1	0–1	5	Greatly widened. Rowland's intensity too low: 2 better

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4419.94	*Mn*	00 N	1–2	7	Widened to red
20.10	*V*	00 N			
4420.45	—	0	00	6	
4421.73	*V*	0	2–3	7	Very broad
4421.93	*Ti*	00	0	3	Perhaps spark line of *Ti*
4422.10	—	1	00–0	6	
4422.98	*Ti*	0	1	7	
4423.30	*Fe*	1	2	7	Broad. Hasselberg gives *V* 4423.32 and *V* 4423.41
23.43	*Cr*	0 N			
4424.01	*Fe?*—	2	1–2	3	Narrow
4424.46	*Cr*	0	1–2	6	Hasselberg gives *Ti* 4424.58
24.53	—	00			
4425.61	*Ca*	4	5–6	7	Winged
4426.20	*Ti*	0 Nd?	2	7	
4427.27	*Ti*	2	3	7	
4427.48	*Fe*	5	7	6	Winged
4428.71	*V–Cr*	1 d?	2	7	
4429.96	*V*	00	1	7	
4430.36	*Fe*	1	0	7	
4430.52	—	00	00–0	3	
4430.78	*Fe*	3	3–4	3	
4431.30	—	0 N	00	5	
4431.52	—	0	0–1	6	Hasselberg gives *Ti* 4431.46
4432.74	*Fe*	1	1–2	4	
4434.17	*Ti*	0 Nd?	1–2	7	
4435.13	*Ca*	5	7	7	Winged
4435.32	*Fe*	2	3	5	
4435.85	*Ca*	4	6	6	Winged
4436.31	*V*	0	1–2	7	
4436.75	—	00	0	6	Hasselberg gives *Ti* 4436.75
4437.11	*Fe–Ni*	2 d?	1–2	4	Narrow
4437.73	—	0	00	6	
4438.01	*V*	0	2	7	
4438.51	*Fe*	1	1–2	4	Very much widened
4440.05	*Fe*	1	2	4	Narrow
4440.52	*Ti*	00	1	6	
4440.99	—	1	0–1	6	
4441.15	*Fe*	0	0	6	
41.26	—	0			
4441.43	*Ti*	00	0	6	
4441.88	*V*, —	3 Nd?	5	7	Very broad
4443.00	*Fe*	1	1–2	6	Narrow
4443.98	*Ti*	5	4	7	Spark line of *Ti*
4444.38	—	0	2–3	7	Rowland's identification *V–Ti* for 4444.57 evidently belongs to this line. Hasselberg gives both *V* and *Ti* here
4444.73	*Fe, Ti*	2	1–2	6	
4445.64	*Fe*	1	2	7	
4447.30	*Mn, Fe*	2	2–3	4	
4447.89	*Fe*	6	8	6	Winged
4449.31	*Ti*	2	3	7	

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4450.65	*Ti?*	2	1–2	6	Narrow. Spark line of *Ti*
4451.09	*Ti*	1	2	6	
4452.17	*V*	0 N	2	7	
4453.17	*Mn*	1	1–2	3	
4453.49	*Ti*	2	3	7	
4453.88	*Ti*	1	2	6	
4454.55	*Fe*	3	3–4	4	
4454.95	*Ca, Zr*	5	7	6	Winged
4455.48	*Mn, Ti*	2	3	6	
4455.98	*Mn*	2	7	7	Winged
56.06	*Ca*	3			
4456.79	*Ca*	2	3–4	7	Perhaps winged
4457.60	*Ti, V, Zr*	2	5–6	6	Strengthened to violet
57.71	*Mn*	2			
4458.24	*Fe?*	2	1–2	6	
4459.52	*Cr*	1	1–2	4	Widened
4459.92	*V*	1	2–3	7	
4460.39	*V*	0	4	7	Rowland's intensity too low: 3 better for total
60.46	*Mn*	1			
60.52	—	0			
4461.82	*Fe*	4	6	6	Much widened
4462.16	*Fe–Mn*	3 Nd?	3–4	7	Widened
4463.57	*Ti–Ni*	0	2	6	Widened to red
63.70	—	00			
63.84	*Ti*	0000			
4464.62	*Ti?*	2	1–2	6	Narrow. Spark line of *Ti*
4464.84	*Mn*	2	3–4	3	
64.94	*Fe*	1			
4465.98	*Ti*	1	2	7	Rowland's intensity too high: 0 better
4466.73	*Fe*	5	6	6	Widened, hazy
4468.66	*Ti*, —	5	4–5	7	Spark line of *Ti*
4469.32	*Ti*	1	0–1	6	
4469.54	*Fe*	4	4	4	Narrow, probably winged
4469.87	*V*	00	0	7	
4470.30	*Mn*	1	1–2	6	
4471.41	*Ti*	0	2	7	
4471.72	—	00 N	1–2	7	Very broad
71.85	—	0			
71.97	—	00			
4472.88	*Fe*	1	2	4	Widened to red. Rowland's intensity too low: 2 better for total
72.97	*Mn*	0			
4473.10	*Ni?*	0	00	6	
4474.21	—	00	0	4	Hasselberg gives *V* 4474.21
4475.03	*Ti*	0	2–3	7	
4475.47	*Cr*	00	0	6	
4476.18	*Fe*	4	8	4	Perhaps winged
76.25	*Ag*	3			
4477.23	—	00	0	3	
4478.19	—	0	0–1	3	
4479.78	*Fe*	1	2	6	Widened to red
79.88	*Ti*	00			

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4480.31	*Fe*	1	2	6	
4480.75	*Ti, Ni*	0 N	0–1	6	
4480.99	—	0	00–0	3	
4481.30	—	0	000	6	Nearly obliterated. Rowland's intensity too low: 1 better
4481.44	*Ti*	1	2	6	
81.52	—	0			
4482.34	*Fe*,—	5	11	6	Much widened
82.44	*Fe*	3			
4482.90	*Ti–Fe*	1	2–3	6	Very hazy
83.04	*Cr*	00			
4484.39	*Fe*	4	4–5	3	
4488.22	*Fe–Cr*	0	2	6	Widened to violet
88.30	—	1			
4488.49	—	1	0	7	Spark line of *Ti*
4488.93	*V*	0000	2	7	Widened to violet
89.08	*Fe*	1			
4489.26	*Ti*	0	3	6	Widened to violet. Spark line of *Fe* at 4489.35
89.35	—	2			
4489.91	*Fe*	4	6	6	
4490.25	*Mn–Fe*	3 N	3–4	6	
4491.57	—	2	0–1	6	Spark line of *Fe*
4491.82	*Cr–Mn*	0	0–1	6	Rowland's intensity too high: 00 better
4492.48	*Cr, Fe*	0	0–1	6	Much widened
4493.70	—	1	0–1	6	Fringe on red side
4494.22	—	1	1–2	6	Much widened
4494.74	*Fe*	6	7–8	6	
4495.18	*Ti*	00	0	6	
4496.32	*Ti*	1	2–3	7	
4497.02	*Cr*	3	4–5	6	Hasselberg gives *V* 4497.03
4497.84	*Ti*	0 N	1–2	7	
4498.90	*Cr*	0	0–1	6	Rowland's intensity too high: 00 better
4499.07	*Mn*	1	1–2	6	Rowland's intensity too low: 2 better
4499.31	—	1	0–1	6	

MOUNT WILSON, CAL.
November 1907

SUN-SPOT BANDS WHICH APPEAR IN THE SPECTRUM OF A CALCIUM ARC BURNING IN THE PRESENCE OF HYDROGEN[1]

By CHARLES M. OLMSTED

In a recent paper by Hale and Adams,[2] it is shown conclusively that numerous flutings which appear in the spectrum of the flame of a titanium arc are present in the spectrum of sun-spots, the flutings with strong heads degraded toward the red at λ 7054.6, λ 7088.0, and λ 7125.9, being especially noticeable. Recently Fowler[3] has called attention to the coincidence of spot bands near the *b* group with the bands of magnesium hydride. Although titanium and magnesium hydride account for many of the band regions in spots, there are, nevertheless, many bands left unidentified. While examining the spectra of various compounds, and of metals under various conditions, in the hope of identifying more of these regions, a band spectrum of calcium burning in the presence of hydrogen was found. This band spectrum, which so far as I know has not been previously noticed, has without doubt its counterpart in the spectra of spots.

There are two main groups of bands: The stronger one at about λ 6385 (Plate VI); the fainter running through the B group. The bands are degraded toward the violet and are built up of rather complexly mixed series of lines. They are similar in appearance to the magnesium hydride bands, and, under low dispersion, present sharply defined heads on the side of greater wave-lengths. The group at λ 6385 has two strong heads (λ 6382.2, λ 6389.3) with less definite and fainter subheads on the red side of these. Heads at approximately λ 6393.0, λ 6398.5, and λ 6407.5 may be noticed.

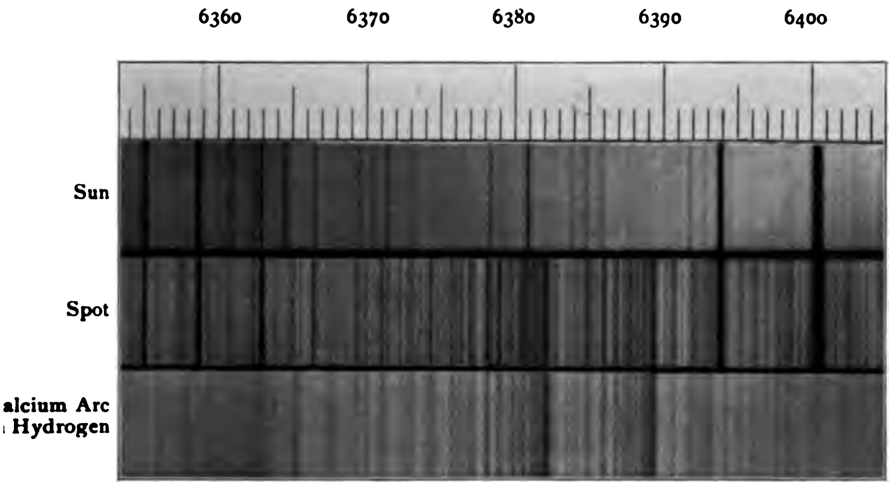
The band group in the B region, although strong and easily photographed when low dispersion is used, is, however, so weak under high dispersion that I have not succeeded as yet in getting a photo-

[1] *Contributions from the Solar Observatory*, No. 21.

[2] "Second Paper on the Cause of the Characteristic Phenomena of Sun-Spot Spectra," *Contributions from the Solar Observatory*, No. 15, *Astrophysical Journal*, **25**, 75–95, 1907.

[3] "The Origin of Certain Bands in the Spectra of Sun-Spots," *Monthly Notices*, **67**, 530–534, 1907.

PLATE VI



Orange Bands Common to the Spectrum of Sun-Spots and to the Calcium Arc Burning in Hydrogen

graph satisfactory for a detailed comparison with the spot spectrum. It should be remarked however, that a very much enlarged copy of a negative taken with an instrument of moderate dispersion (a heavy flint 60°-prism used in a Littrow spectrograph of twelve feet (366 cm) focal length) shows beyond a doubt that this group also is in spots. The structure of these bands is in some ways very similar to the group at λ 6385. The discussion of this point is reserved until a stronger high-dispersion photograph is obtained.

It seems very probable from the following facts that the spectrum under consideration is due to some compound of calcium and hydrogen:

The bands appear when an arc formed between metallic calcium electrodes burns either in commercial hydrogen or in hydrogen formed from zinc and hydrochloric acid and dried with sulphuric acid; but do not seem to appear when the same electrodes form arc in air.

Also these bands do not appear when dry calcium carbide is used as electrodes in air; but do appear if wet cotton surrounds the electrodes.

The bands appear when calcium metal electrodes are burned in air if a stream of steam or hydrogen enters the arc through a hole bored in one electrode.

The spectrum from which Plate VI was made was obtained by burning a calcium arc of from five to twenty amperes in an atmosphere of commercial hydrogen at atmospheric pressure. The arc was formed between a stationary copper rod as negative electrode and a rotating calcium disk as positive electrode. The first-order spectrum of a Littrow spectrograph of eighteen feet (549 cm) focal length with a six-inch (15.24 cm) grating of 14,438 lines to the inch (5684 lines to the cm) was used. With a slit width of 0.003 inch (0.075 mm) a net exposure of two hours with a Wrattan & Wainwright panchromatic plate was necessary.

It should be mentioned that while testing calcium carbide in air to see if the spectrum were due to the carbide, some bands in the green, due to calcium carbide, were noted. These are beautiful strong bands degraded toward the red; but as they do not appear in spots, their discussion does not belong to this communication.

The following table of wave-lengths indicates the agreement which exists between the individual lines of the bands of the spectrum

Sun-Spot		Ca in H_2		Notes	
λ	Int.	λ	Int.	Spot	Ca in H_2
6369.45	6	.39	6	Center of wide blend	Center of wide blend
70.16	4	.10	4	Maximum of wide blend	Maximum of wide blend
70.55	1				
70.80	1	.76	1		Double
71.14	10	.16	8		
71.57	5	.63	1		
72.37	6	.37	5		
72.88	5	.89	5	*Ti* line at 72.86	
73.23	5	.23	4		
73.67	2	.66	1	Wide	Double
74.03	1	.02	1	Double	Double
74.42	14	.42	10		
74.94	2	.99	2		
75.29	2	.31	1		
75.80	6	.80	8		Wide
76.07	2				
76.47	6	.46	4		
76.64	1	.62	1		
77.08	8	.17	5	Wide	Wide
77.39	4			Hazy *Ti* line at 77.27	
78.18	12	.15	12	Double	Double
78.48	2				
79.00	16	.00	10	Wide	Wide
79.57	3	.60	1	*Ti* line at 79.54	
79.93	4	.93	7		
80.23	2				
80.62	10	.62	8	Blurred triplet	Wide
80.97	6			Double	
81.26	8	.26	8		
81.61	8	.65	5		Double
81.96	6	82.02	6		
82.21	16	.25	20		
		82.41	2		
		82.62	1		
82.81	3	.79	2		
82.98	1				
83.38	1				
83.57	2	.56	2	Double	Double
84.02	4	83.97	4		
84.31	4	.31	4		
84.91	9	.91	6	Wide (triplet)	Wide
85.60	3	.57	2		
86.04	12	.04	11	Wide	Wide
86.91	9	.95	8	Maximum measured—has violet wing	
87.31	4	.35	2		
87.68	5	.63	4	*Ti* line at 87.70	
87.84	5	.86	3		
87.91	3	.92	3		
88.71	6	.67	6	Maximum	Maximum
89.02	2	88.98	2	*Ti* line at 88.99	
89.34	16	.33	20	Double	Double
89.79	1				
90.05	2	.00	1		

Sun-Spot		*Ca* in H_2		Notes	
λ	Int.	λ	Int.	Spot	*Ca* in H_2
6390.17	4	.19	4		
90.68	10	.68	10	*Ti* line at 90.65	Wide
91.26	4				
91.68	2	.68	2		
91.94	6	.93	6	*Ti* line at 92.03	
92.35	2	.35	2		
92.61	1				
92.75	3	.80	1		
93.18	4	.18	5	[*Fe* 7	
93.81	50	.80	2	Solar line at 6393.820	
94.48	6	.48	6		
95.00	4	.02	4	*Ti* line at 94.93	
95.31	6	.32	4		
96.03	4				
		96.16	1		
96.25	5	.26	5		
96.58	1	.58	2		
		96.78	1		
96.89	4				
97.07	4	.05	4		
97.58	2				
97.66	6	.68	6		
98.45	9	.44	6	Double	Double
98.49	5	.48	4		
		99.33	2		
99.70	4	.65	3		
		99.84	1		
6400.22	60			Solar line 6400.217 *Fe* 8	
		00.27	6		
00.56	40	.59	2	Solar line 6400.538 *Fe* 2	
01.09	2	.15	2	Wide	Wide
01.56	6			Wide: *Ti* line at 01.48	
02.03	4	.04	4		
02.34	4				
02.49	6	.48	8		
02.94	4	.98	4		
03.58	6	.50	4	*Ti* line at 03.56	
04.32	2	.37	2	Double	Wide

of the calcium arc burning in hydrogen and those of the sun-spot spectrum. The scale of intensities is purely arbitrary, the larger numbers indicating greater intensities. Out of eighty-four spot lines (all that could be distinctly seen between λ 6389 and λ 6405) sixty-two are matched to within 0.05 tenth-meters by band lines of *Ca* in hydrogen. Within this same region there are twelve lines of the calcium spectrum which are not matched to within 0.05 tenth-meters by spot-lines. Probably five of these disagreements are due to errors of measurement greater than 0.05 tenth-meters, the remainder to impurities.

Mount Wilson
November 1907

WAVE-LENGTHS OF TITANIUM $\lambda\lambda$ 3900 AND 3913 IN ARC AND SPARK

BY NORTON A. KENT AND ALFRED H. AVERY

In June 1905 one of us (Kent) published the results of a careful series of experiments dealing with the variation in wave-length of certain lines of the spark-spectra of titanium, iron, and zinc with the electrical conditions of the discharge.[1] Subsequently Keller, working under Kayser, published a paper[2] in which the suggestion was made that the apparent non-coincidences of the spark and the comparison arc lines were due to the fact that the slit was not accurately adjusted to parallelism with the grating ruling; and the statement was made that the plumb-line method of adjustment employed by the writer was of less delicacy than the spectroscopic.

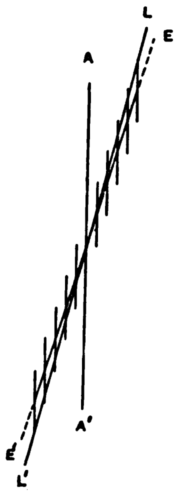


FIG. 1.—AA', direction of grating ruling; EE', direction of slit; LL', direction of resultant line.

The substance of Keller's explanation of the manner in which shifts could be introduced by orientation of the spectrometer slit is as follows: Given a perpendicular grating ruling, an astigmatic instrument such as the concave grating will give a perpendicular line image for every point of the line source as object. If, then, this line source or slit be at an angle (say clockwise as one faces it) with the grating ruling, the spectral line will be a composite of lines arranged as in Fig. 1.

The result will be an image which is apparently rotated in the direction of the slit. If, then, on one photographic plate two exposures be made, one each of arc and spark, and the position of the adjacent tips of the images of any spectral line be measured by a comparator, any displacement desired may be introduced by a rotation of the slit.

But Keller's explanation does not apply to the method of exposure

[1] *Proceedings of the American Academy of Arts and Sciences*, 41, No. 10, July 1905.

[2] *Ueber die angebliche Verschiebung der Funkenlinien*, Inaugural-Dissertation, 1906.

employed by Kent—a method of triple exposure, two of the arc (the first and the third) superimposed horizontally but not wholly vertically and spanned by the spark exposure.

It is difficult to see how non-parallelism of slit and ruling could in this case introduce a shift. Keller seems to have overlooked the fact that this triple method was employed, for no mention is made of it in his paper. However, despite the fact that it was not apparent how the above-mentioned criticism could apply, it seemed advisable to test the matter, and the following experiments were undertaken to decide the two following questions:

1. Is the plumb-line method of adjustment of slit and grating ruling to parallelism more or less accurate than the spectroscopic?

2. Will an orientation of the slit introduce a shift if the triple method of exposure be used?

CONDITIONS OF EXPERIMENT

The conditions under which the present work was carried on were, as far as possible, those of the previous series of experiments. By the courtesy of Professors Trowbridge and Sabine every facility of the Jefferson Physical Laboratory was placed at our disposal. The 6-inch Rowland concave grating—with 20,000 lines to the inch and 21 feet radius of curvature, an excellent instrument—was kindly loaned by Professor Trowbridge, and the mount was that belonging to the laboratory and located on the third story of the building. The beams were heavy timbers supported wholly from the wall. The slit, grating-holder, camera-box, rheostat, transformer, and condenser were those used in the former work. The usual precautions relative to temperature changes were taken, the whole mount being wrapped in several layers of newspaper. The vibrations of the building due to wind and heavy machinery necessitated working at times when these disturbing influences were absent. All plates which did not show horizontal coincidence of the arc exposures were rejected. The current used for both arc and spark was the 110-volt, 66-cycle, alternating current of the Cambridge Electric Light Company. The frequency of the current used in the previous work was 133, but as the transformer was built for 66 cycles no difficulty was experienced in this regard. The voltmeter, ammeter, and wattmeter were of

Thompson form and of ranges, 0–65 volts; 0–60 amperes; 0–45 hecto-watts, respectively. Thus the conditions were the same as those formerly employed in all respects except location, frequency of current, and grating.

RESULTS OBTAINED

1. *Relative merits of plumb-line and spectroscopic methods of adjustment.*—The grating-holder was fitted with two opposing screws moving in a horizontal plane and controlling the orientation of the grating. It was found by trial that by the unaided eye the parallelism of either end of the ruled space of the grating with the silk thread of a plumb-line suspended from the grating-holder could be adjusted so that the separate settings made by each of us agreed to within 45° on the head of one of the screws. This means that the grating can be set by plumb-line to within 3.3 minutes of arc.

Opening the slit and hanging the bob so that the thread could be seen through it, the various settings made by each of us agreed to 10° on a divided head fitted to the tangent screw. This means by calculation 1.7 minutes of arc of rotation of the slit.

On the other hand, using full length of slit as in the previous case and appropriate width, about $\frac{1}{1000}$ inch, various exposures of the arc were taken on the same plate in the manner customary in making focus plates except that the camera-box was left clamped and the slit was oriented. These plates showed no difference in the spectra when the scale on the divided head of the tangent screw was rotated 90° clockwise or counter-clockwise from the position of parallelism as determined by plumb-line, making a change of 15.3 minutes in the orientation of the slit—a change nine times as great as that in the case of the plumb-line. However, the relative merits of the two methods must not be taken as nine to one, but merely as about four to one, for the plumb-line adjustment for the grating is only about one-half as accurate as that for the slit.

The above facts make it extremely probable that the adjustment of the slit in the previous investigation was good. And, further, if with full length of slit no change in definition could be detected for a rotation of 90°, it is all the more probable that with a slit of 5 mm in length, as used in making regular exposures, the definition was the best obtainable.

2. Further, as to *shift as a function of orientation of the slit*, a series of plates was taken with the slit oriented approximately 1° and 0°.5 clockwise and counter-clockwise, including a series at parallelism or 360° and 180° counter-clockwise, 0°, and 180° and 360° clockwise on the divided head. If orientation introduce shift, the shift-orientation curve should either show a point of inflection at zero orientation or cross the displacement axis at that point. Tables I and II are self-explanatory. The data therein given show that for the two lines studied neither of the above possibilities is realized. The shift is not influenced by the orientation of the slit but is, within the limits of error of the experiment, constant at all orientations investigated.

The agreement between the means obtained formerly by Kent and those given in the present investigation is as close as could be expected.

Particulars of Table I

Metal used; Titanium Carbide, 85 per cent. *Ti.*, 15 per cent. *C.*
Arc vertical; length 3 mm; spark horizontal; length 9 mm.
End of spark image always used.
Capacity of condenser, 0.0226 microfarads.
Times of exposures, arc, 5+5 seconds; spark, 75 seconds.
Plates, Seed, Gilt Edge, No. 27.
Developer, metol, adurol, hydrochinon.
Second order spectrum.
Width of slit, 0.025 to 0.050 mm; length, 5 mm.
Length of grating lines used, 14 mm.

TABLE I

SHIFT OF SPARK LINES TOWARD RED FROM POSITION OF ARC LINES
ORIENTATION OF SLIT, CLOCKWISE 360°

PLATE No.	AMPERES	VOLTS	WATTS	SHIFT IN TENTH-METERS			
				λ 3900.68		λ 3913.58	
				Kent	Avery	Kent	Avery
19......	....	....	...	0.035	0.041	0.030	0.035
20......	....	....	...	21	31	18	28
52......	39.0	19.0	...	32	42	31	26
54......	40.0	18.8	...	16	23	16	20
88......	41.0	16.0	450	25	21	18	12
89......	40.5	16.0	450	18	26	21	23
122......	41.3	19.0	500	14	14	12	12
123......	41.3	17.0	500	13	12	12	16
124......	41.5	17.0	500	11	10	7	14

TABLE I—*Continued*

CLOCKWISE 180°

Plate No.	Amperes	Volts	Watts	Shift in Tenth-Meters λ 3900.68 Kent	λ 3900.68 Avery	λ 3913.58 Kent	λ 3913.58 Avery
35......	40.0	16.5	...	0.020	0.027	0.026	0.022
36......	40.0	16.5	...	12	22	10	19
49......	40.0	18.0	...	15	20	18	17
51......	39.3	18.0	...	14	13	15	15
85......	40.5	17.0	490	20	18	19	24
87......	41.0	16.5	450	20	21	16	20
119......	41.5	19.5	520	15	18	16	25
120......	42.0	17.5	480	13	22	13	18

PARALLEL, OR 0°

Plate No.	Amperes	Volts	Watts	λ 3900.68 Kent	λ 3900.68 Avery	λ 3913.58 Kent	λ 3913.58 Avery
32......	38.5	19.0	...	0.019	0.023	0.015	0.017
39......	39.0	21.0	...	27	28	23	24
40......	40.5	17.0	...	7	13	4	12
44......	39.8	19.0	...	29	30	29	33
45......	40.0	19.0	...	25	21	21	29
48......	37.5	21.5	...	18	18	14	17
63......	41.0	16.0	500	14	18	16	17
68......	39.0	19.0	500	8	10	5	5
72......	40.0	17.5	490	23	23	23	25
74......	39.5	17.5	450	39	29	42	34

COUNTER-CLOCKWISE 180°

Plate No.	Amperes	Volts	Watts	λ 3900.68 Kent	λ 3900.68 Avery	λ 3913.58 Kent	λ 3913.58 Avery
76......	40.0	22.0	500	0.025	0.019	0.024	0.029
77......	40.0	19.0	450	16	10	16	8
78......	40.0	19.0	450	32	42	32	27
83......	41.0	15.0	450	25	26	20	18
101......	40.0	17.0	450	8	12	6	19
102......	39.0	19.0	450	11	9	14	14
116......	41.0	19.0	550	14	19	13	10
117......	41.8	18.5	550	18	16	15	10

COUNTER-CLOCKWISE 360°

Plate No.	Amperes	Volts	Watts	λ 3900.68 Kent	λ 3900.68 Avery	λ 3913.58 Kent	λ 3913.58 Avery
21......	....	....	...	0.012	0.012	0.014	0.013
22......	....	....	...	29	34	27	40
23......	40.8	15.5	...	10	23	11	13
26......	42.0	15.5	...	6	20	8	16
58......	40.0	19.3	...	12	16	15	15
82......	40.0	19.0	500	28	23	24	22
110......	41.0	19.0	450	12	7	12	9
112......	42.5	15.0	450	15	9	14	12
114......	41.0	15.5	450	14	11	13	14

TABLE II

SUMMARY OF TABLE I

λ 3900.68

Orientation		Clockwise 360°	Clockwise 180°	0°	Counter-Clockwise 180°	Counter-Clockwise 360°
Means	Kent	0.021	0.016	0.021	0.019	0.015
	Avery	24	20	21	19	17

λ 3913.58

Means	Kent	0.018	0.017	0.019	0.018	0.015
	Avery	21	20	21	17	17

	λ 3900.68 Kent	λ 3900.68 Avery	λ 3913.58 Kent	λ 3913.58 Avery
Means of Means at All Orientations	0.018	0.020	0.017	0.019
Weighted means of all measurements	0.019		0.018	
Weighted means at parallelism	21		20	
Means as given by previous investigation under similar conditions	19		18	

The average deviation from the mean of two measurements (of the shift of a line) on any one plate is 0.003 (Kent) and 0.004 (Avery) t.-m. for λ 3900.68; and 0.002 (Kent) and 0.003 (Avery) t.-m. for λ 3913.58. It will be noticed that the value of the shift given on the different plates varies considerably. This is probably due to the fact that it was difficult to set the very end of the spark image accurately upon the slit. As shown in the previous paper the part of the image employed influences the character of the line and the value of the shift.

During the progress of the work it was suggested to us that the use of the tip of the spark line as that part of the line upon which to set the thread of the microscope in measuring was perhaps objectionable owing to the fact that there might be a shift due to diffraction resulting from reducing the virtual aperture of the grating by strips of black paper set only *roughly* perpendicular to the ruling, the measurement being made by a mm scale. Three exposures on one

plate were therefore made—all of the arc, and the first and third superimposed as usual. No shift was shown when the slit was either parallel or oriented as indicated in Table III.

TABLE III

ARC AND ARC

Plate No.	Orientation of Slit							
	λ 3900.68				λ 3913.58			
	Parallel, or 0°		Counter-clockwise 360°		Parallel, or 0°		Counter-clockwise 360°	
	Kent	Avery	Kent	Avery	Kent	Avery	Kent	Avery
106....	−0.001	0.003			−0.002	0.002		
107....	1	2			4	3		
109....			2	5			3	2

At the end of the series of experiments the water rheostat was cut out of the transformer circuit and in its place was inserted a choke coil of closed magnetic circuit of U-form with adjustable armature. When adjusted roughly to show maximum power as measured by the wattmeter, with a spark length as indicated in Table IV, the shift was increased to 0.032 t.-m. in the mean for λ 3900.68 and 0.033 t.-m. for λ 3913.58.[1]

TABLE IV

(Conditions same as in Table 1, except spark length = 9 mm in Plate 125 and 15 mm in Plates 126 to 128. Time of exposures for spark = 60 seconds.)

Plate No.	Conditions of Primary Circuit			Orientation of Slit: Parallel, or 0°			
				λ 3900.68		λ 3913.58	
	Amperes	Volts	Watts	Kent	Avery	Kent	Avery
125......	50	28	1,000	0.040	0.038	0.031	0.040
126......	49	27	950	33	33	30	49
127......	50	24	800	30	30	32	29
128......	50	26	800	26	29	22	31
Means...				32	32	29	37

[1] At the request of the writer Mr. Walter S. Adams of the Carnegie Solar Observatory kindly measured Plate No. 126 upon one of the Observatory comparators and obtained values of 0.040 and 0.038 for λλ 3900 and 3913 respectively.

It is the purpose of the writer of the former paper to study with an echelon the position of the narrow and less diffuse lines of the titanium spectrum.

In conclusion we wish to acknowledge the kindness shown us by Professor Trowbridge and those associated with him in so generously putting at our disposal all the facilities of the Jefferson Physical Laboratory; and our thanks are due also to the Rumford Committee for the grant made in aid of this research.

Department of Physics
Boston University
November 1907

THE LARGE PROMINENCE OF MAY 21, 1907

By J. FÉNYI

In the October number of this *Journal* (**26**, 155, 1907) Mr. Fox contributed a paper, illustrated with four photographs, on this phenomenon, somewhat unusual at our present very feeble maximum. As this eruptive prominence was observed, sketched, and measured at precisely the same time in Kalocsa, it will be of interest to compare these visual observations with the photographic results.

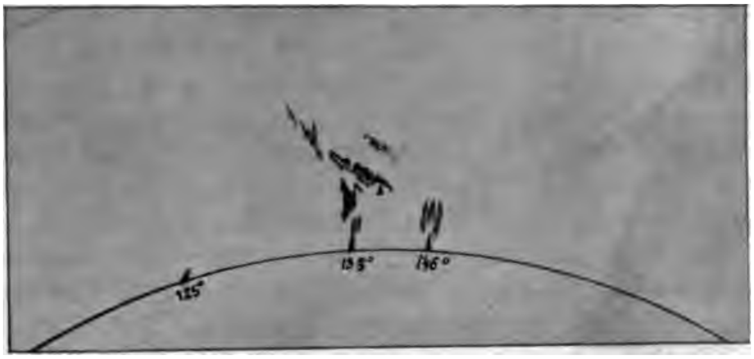
Having seen the prominence on his first exposure, Fox began at $4^h\ 52^m$ G. M. T. to take photographs of it in rapid succession. At the same time I had just completed the sketch of the prominence and began to measure its height by means of transits across the slit. The time of the first transit was not noted, but it can be deduced from the data after the seventh transit, and is put at $4^h\ 52^m$—that is, at the very moment when Fox made his second exposure. I observed successively eleven transits concluding at $5^h\ 3^m$. The eighth transit at $5^h\ 0^m$ coincides roughly with Fox's third exposure. The observed heights follow:

G. M. T.	Photographic	Visual	Ph.−V.
$4^h\ 52^m$........	259″	190″	69″
5 02	280	226	54

The visual spectroscopic observations give lower altitudes than the photographic. The atmospheric conditions in Kalocsa were unfavorable, as also at the Yerkes Observatory. After $5^h\ 3^m$ the conditions were so bad that observations were given up. On the following day, nineteen hours later, with favorable atmospheric conditions, no prominence was visible at this position.

The accompanying sketch shows the form as drawn at Kalocsa only a few minutes before the first transit. This should therefore agree with Fox's photograph No. 2. We find, however, such differences that no part of them can be identified: for example, in Kalocsa a column was seen resting on the chromosphere, which is lacking in the photograph. The sketch on the whole much more strongly recalls No. 1, which, however, was exposed fifty minutes earlier.

The rapid ascent of the prominence was also observed in Kalocsa. The first seven transits considered successively reveal the ascension, which between $4^h\ 52^m$ and $5^h\ 0^m$ amounted to 36″, that is, at a rate of 54 km per second. The simultaneous exposures of Fox, Nos. 2 and 3, give only 30 km. The difference is considerable, but it can be ascribed to the uncertainty of my estimated time and to the indefiniteness of the object (the upper filaments were very weak), even aside from the fact that we did not measure strictly the same object, since a hydrogen prominence was observed visually while a calcium



Prominence as observed at Kalocsa, May 21, 1907; height, 226″

prominence was measured on the photographs. I must also remark that during the eleven transits, which covered twelve or fifteen minutes, no change of form was noticed: all the parts, as they are shown in the sketch, passed in the same relative position, successively across the slit.

I have never observed the subsidence of a prominence of great height, say of over 240″. Rapidly rising prominences have always as quickly dissipated themselves at great elevations, thus yielding a lower altitude. At less heights, somewhere under 60″, the subsidence is seen not seldom; for very small prominences of about 20″ altitude the descent is the usual occurrence. It would certainly be of the greatest importance for the theory of prominences if the subsidence of one that had reached great elevations might be proved photographically.

HAYNALD OBSERVATORY
Kalocsa, Hungary

Minor Contributions and Notes

STARS HAVING PECULIAR SPECTRA. FIFTEEN NEW VARIABLE STARS[1]

An examination of the photographs of the Henry Draper Memorial, by Mrs. Fleming, has led to the discovery of a number of variable stars and other objects having peculiar spectra. A list of these is given in Table I. The constellation and *Durchmusterung* number are given in the first two columns. The approximate right ascension and declination for 1900 and the catalogue magnitude are given in the third, fourth, and fifth columns. The designations for stars north of declination $-23°$ are taken from the *Bonn Durchmusterung*. For stars between $-23°$ and $-52°$ the *Cordoba Durchmusterung*, and for stars south of declination $-52°$ the *Cape Photographic Durchmusterung* is used. The class of spectrum and a brief description of the object are given in the sixth and seventh columns. Each of the new variables has been confirmed by Miss L. D. Wells, unless otherwise specified. Additional information regarding these objects is given in the Remarks following the table. In the case of new variable stars, the right ascension is followed by the designation, described in *H.A.*, **48**, 93, which gives the approximate position, and also the designation described in *H.A.*, **53**, 147, which indicates the number in the series of variables found at Harvard. This last number is also given in the table, for convenience of future reference.

The star $+66°780$ is given by Dunér and by Krüger as of the fourth type. It was announced as a variable in *H.C.*, 124. The spectrum appears to change on the photographs available for examination. On Plate I 3247, taken on March 5, 1891, the spectrum is faint but clearly shown and contains no bright line. On Plate I 12509, taken on March 14, 1895, the object is near the edge of the plate. No part of the continuous spectrum is visible, but the bright line $H\beta$ is well defined and easily seen. On Plate I 12724, taken on

[1] *Harvard College Observatory Circular*, No. 132.

April 19, 1895, the line $H\beta$ appears as a strong bright line, and the portion of the continuous spectrum shown is of shorter wave-length than $H\beta$, and does not extend beyond $H\gamma$. On Plate I 33878, taken on February 22, 1906, the line $H\beta$ appears as a strong bright line, and the brightest and best-defined portion of the spectrum is of greater wave-length than $H\beta$, but the portion between $H\beta$ and $H\gamma$ is also well shown, although about half a magnitude fainter than the part of greater wave-length than $H\beta$. On Plate I 34569, taken on March 7, 1907, the line $H\beta$ appears as a faint bright line, while the continuous spectrum is well shown and is similar to that on Plate I 33878. The object is difficult to describe on these plates, since all were taken with the 8-inch Draper Telescope using a small prism, and the portion visible on the individual plates amounts to 1.8, 0.1, 0.7, 1.6, and 1.8 millimeters, respectively. Plate I 10978, taken with the same telescope, using an 8° prism, shows a very faint spectrum which is similar to that on Plates I 33878 and I 34569.

TABLE I

PECULIAR SPECTRA

Constellation	B. D.	R. A. 1900	Dec. 1900	Mag.	Spectrum	Description
		h. m.	° ′			
Aries	+11°305	2 9.6	+11 46	8.9	Pec.	Variable?
Auriga	+45.1324	6 28.2	+45 43	8.7	Mc	Variable. H 2992
Monoceros	− 4.1708	6 48.3	− 4.27	9.0	Na	Variable. H 2993
Canis Major ...	−22.1850	7 19.4	−22 47	9.1	Na	Variable. H 2994
Cancer	+15.1808	8 16.8	+15 19	8.6	Mc 5 d	Variable. H 2995
Ursa Major	....	9 44.4	+53 7	...	Pec.	Dark bands
Vela	−49.5234	10 21.0	−49 54	9.6	Pec.	Dark bands
Carina	−72.1048	10 48.7	−72 14	9.8	Mb 5 c	Variable. H 2996
Musca	R	11 35.0	−72 0	8.5	Na	Variable. H 2997
Virgo	....	12 0.0	+12 56	...	Md	Variable. H 2998
Musca	R	12 17.4	−74 57	9.5	Na	Variable. H 2999
Corvus	−16.3503	12 32.3	−16 43	9.6	Mc 5 d	Variable. H 3000
Centaurus	−63.2720	13 15.5	−63 42	9.5	Na	Variable. H 3001
Centaurus	−56.5891	13 36.4	−56 16	6.8	Pec.	Class A, peculiar
Circinus	−67.2622	14 30.9	−67 46	7.0	Pec.	$H\beta$ bright
Corona Borealis	+39.2901	15 37.8	+38 53	7.0	Mc 5 d	Variable. H 3002
Draco	+57.1786	17 35.4	+57 48	9.3	Mc 5 d	Variable. H 3003
Ophiuchus	+ 6.3898	18 37.1	+ 6 43	9.0	Pec.	Dark bands
Aquila	....	20 7.1	+11 35	...	Pec.	Bright line. Type V
Draco	+74. 861	20 25.9	+74 56	9.3	Mc 5 d	Variable. H 3004
Cygnus	+32.3850	20 27.6	+32 14	9.1	Na	Variable. H 3005
Pegasus	+34.4597	22 1.4	+34 52	8.5	Mc 5 d	Variable. H 3006
Aquarius	−21.6376	23 6.3	−21 32	9.0	Pec.	Dark bands

REMARKS

h m
2 9.6. An examination of twenty-four chart plates, taken between January 13, 1890, and September 6, 1905, shows a small but distinct variation in the light of this star. On several plates it is about 0.2 magnitude fainter than +11°.303, mag. 9.5 (assumed photographic magnitude 8.6), while on others it is about 0.3 to 0.4 magnitude brighter than that star. Estimates from these plates gave the approximate limiting magnitudes, 8.2 to 8.8.

6 28.2. 062845 = H. V. 2992. An examination of this star on twenty-one chart plates, taken between March 3, 1890, and March 11, 1905, shows a variation of about 0.9 mag. Estimates from these plates gave the approximate limiting magnitudes, 8.5 to 9.4.

6 48.3. 020911 = H. V. 2993. The spectrum of this star is already known as Type IV. An examination of sixteen chart plates of this object, taken between February 22, 1891, and November 11, 1904, shows a variation of about 1.2 mag. Estimates from these plates gave the approximate limiting magnitudes, 9.2 to 10.4.

7 19.4. *071922* = H. V. 2994. An examination of this star on twenty-one chart plates, taken between April 17, 1894, and November 30, 1904, shows a decided although small variation of 0.9 mag. Estimates from these plates gave the approximate limiting magnitudes, 11.0 to 11.9.

8 16.8. 081615 = H. V. 2995. An examination of this star on eighteen chart plates, taken between February 14, 1899, and January 30, 1906, shows a variation of about 0.9 mag. Estimates from these plates gave the approximate limiting magnitudes, 9.4 to 10.3.

9 44.4. This spectrum is faint, but is apparently of the same type as *C.DM.* −47°.6614, described in *H.C.* 76.

10 21.0. This spectrum is of the same type as *C.DM.* −47°.6614, described in *H.C.* 76.

10 48.7. *104872* = H. V. 2996. An examination of this star on eighteen chart plates, taken between April 1, 1890, and May 12, 1905, shows a variation of about 1.7 mag. Estimates from these plates gave the approximate limiting magnitudes, 9.8 to 11.5.

11 35.0. *113572* = H. V. 2997. This star is *A.G.C.* 15946 and is known to have a spectrum of Type IV. An examination of eighteen chart plates of this object, taken between April 1, 1890, and May 12, 1905, shows a variation of about 1.6 mag. Estimates from these plates gave the approximate limiting magnitudes, 8.6 to 10.2.

12 0.0. 120012 = H. V. 2998. An examination of this star on fourteen chart plates, taken between April 25, 1891, and May 9, 1905, shows a variation of about 4.0 mag. Estimates from these plates gave the approximate limiting magnitudes, 8.5 to 12.5.

12 17.4. *121774* = H. V. 2999. This star is *A.G.C.* 16865. An examination of sixteen chart plates of this object, taken between May 2, 1893, and March

29, 1905, shows a variation of about 1.8 mag. Estimates from these plates gave the approximate limiting magnitudes, 8.8 to 10.6.

12 32.3. *123216*=H. V. 3000. An examination of this star on twenty chart plates, taken between April 1, 1890, and May 12, 1905, shows a variation of about 1.7 mag. Estimates from these plates gave the approximate limiting magnitudes, 8.8 to 10.5.

13 15.5. *131563*=H. V. 3001. The spectrum of this star is already known as Type IV. An examination of eighteen chart plates of this object, taken between May 24, 1889, and January 30, 1901, shows a variation of about 1.5 mag. Estimates from these plates gave the approximate limiting magnitudes, 9.0 to 10.5.

13 36.4. On Plate B 5271, taken on May 25, 1890, the hydrogen lines are very faint and narrow in the spectrum of this star. On Plate B 36285, taken on June 24, 1905, the lines $H\beta$ and $H\gamma$ are bright on the edge of greater wave-length, while $H\delta$, $H\epsilon$, and $H\zeta$ appear as broad dark bands with narrow bright lines superposed toward the edge of shorter wave-length. These give the spectrum on this plate the appearance of being that of a spectroscopic binary.

14 30.9. On Plate B 36127, taken on May 27, 1905, $H\beta$ appears as a faint bright line.

15 37.8. 153738=H. V. 3002. An examination of this star on twenty-eight chart plates, taken between June 2, 1892, and February 11, 1907, shows a variation of about 1.3 mag. Estimates from these plates gave the approximate limiting magnitudes, 7.0 to 8.3.

17 35.4. 173557=H. V. 3003. Variability suspected by Espin. *A. N.*, **145**, 327. An examination of this star on twenty-one chart plates, taken between August 17, 1892, and October 10, 1902, shows a variation of about 1.7 mag. Estimates from these plates gave the approximate limiting magnitudes, 8.0 to 9.7.

18 37.1. This spectrum is of the same type as *C.DM.*−47°6614, described in *H.C.*, 76.

20 7.1. Galactic longitude, 20° 45′. Galactic latitude, −13° 6′. In Heis's Atlas, Plate VII, in *Aquila*, in Plate XII, near border of *Delphinus*.

20 25.9. 202574=H. V. 3004. An examination of this star on nine chart plates, taken between October 18, 1894, and October 28, 1903, shows a variation of about 2.2 mag. Estimates from these plates gave the approximate limiting magnitudes, 8.3 to 10.5.

20 27.6. 202732=H. V. 3005. An examination of this star on ten chart plates, taken between August 4, 1890, and November 9, 1905, shows a variation of about 1.0 mag. Estimates from these plates gave the approximate limiting magnitudes, 8.5 to 9.5.

22 1.4. 220134=H. V. 3006. An examination of this star on twenty chart plates, taken between December 22, 1890, and September 27, 1905, shows a

variation of about 1.0 mag. Estimates from these plates gave the approximate limiting magnitudes, 8.2 to 9.2. This object was found to be variable by Mrs. Fleming on November 26, 1904, but since the change was slight, about half a magnitude, on the plates examined, publication was withheld until the star was rediscovered independently by Miss Leavitt in her examination of the Harvard Maps of the Sky. She found a change of about 0.7 mag.

23 6.3. This star is announced as of Type IV in *Astronomy and Astrophysics*, 12, 546. On Plate A 8155, taken with the 24-inch Bruce Telescope, on October 11, 1906, a good image of the spectrum of this star shows that it is of the same type as *C.DM.*$-47°6614$, described in *H.C.* 76.

EDWARD C. PICKERING

OCTOBER 15, 1907

CORRECTION TO MR. WALLACE'S ARTICLE IN THE DECEMBER NUMBER

In Mr. Wallace's article entitled "Studies in Sensitometry. II. Orthochromatism by Bathing," through an unfortunate blunder on the part of the printer, the final paragraph (p. 325) was allowed to stand, while it should have been omitted. The failure of the engravers properly to reproduce the author's illustrations made it necessary to omit the plate, which was at first intended to accompany the paper. The last four lines of the article, constituting the final paragraph, should therefore be stricken out.

The small plate on p. 300 is also a very unsatisfactory representation of the author's spectra, and the words "*Li* λ 6103" should be crossed off, as the engraving fails to show the line intended.

Also in footnote 2 on p. 304, for "battered plates" read "bathed plates."

EDITORS

OBITUARY NOTICE

We record with deep regret the recent decease of two eminent astrophysicists, chiefly distinguished for their researches in solar physics.

PIERRE JULES CÉSAR JANSSEN,

director of the Astrophysical Observatory, Meudon, died at Paris on December 23, 1907, in the eighty-fourth year of his age.

CHARLES AUGUSTUS YOUNG,

emeritus professor of astronomy in Princeton University, an editorial collaborator of this *Journal* since its foundation, died at Hanover, N. H., on January 3, 1908, at the age of seventy-three years.

Appropriate accounts of the lives and works of these scientists will appear later in the columns of this *Journal*.

NOTICE

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention is given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric, and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* shorter articles will generally be placed and subjects may be discussed which belong to other closely related fields of investigation.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with the red end on the right, unless the author requests that the reverse procedure be followed.

Accuracy in the proof is gained by having manuscripts type-written, provided the author carefully examines the sheets and eliminates any errors introduced by the stenographer. It is suggested that the author should retain a carbon or tissue copy of the manuscript, as it is generally necessary to keep the original manuscript at the editorial office until the article is printed.

All drawings should be carefully made with India ink on stiff paper, usually each on a separate sheet, on about double the scale of the engraving desired. Lettering of diagrams will be done in type around the margins of the cut where feasible. Otherwise printed letters should be put in lightly with pencil, to be later impressed with type at the editorial office, or should be pasted on the drawing where required.

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Authors are particularly requested to employ uniformly the metric units of length and mass; the English equivalents may be added if desired.

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VOLUME XXVII NUMBER 2

THE ASTROPHYSICAL JOURNAL

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CONTENTS

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THE

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AND ASTRONOMICAL PHYSICS

VOLUME XXVII MARCH 1908 NUMBER 2

THE ABSORPTION OF SOME GASES FOR LIGHT OF VERY SHORT WAVE-LENGTH

By THEODORE LYMAN

The only data on the absorption of gases for light more refrangible than λ 1850 have been collected by Victor Schumann. He has investigated[1] the behavior of oxygen, hydrogen, nitrogen, carbon monoxide, carbon dioxide, and water vapor. The results are of extreme importance and interest, but their value is somewhat limited by the nature of the instrument which was used to carry on the work: for Schumann's prism spectroscope could not give information as to the wave-length of the light which it analyzed; and moreover, because of its inherent aberrations, the results which it yielded were exposed to some slight error if the work extended over a considerable spectral region.

It seemed worth while, therefore, both on practical and theoretical grounds, to go over the work with the aid of the vacuum-grating spectroscope. Accordingly, the absorption of hydrogen, oxygen, nitrogen, carbon monoxide, and carbon dioxide has been investigated and to these gases treated by Schumann argon and helium have been added. The results are in good general agreement with those obtained by the earlier investigator with the exception of the facts which relate to the absorption of oxygen. From Schumann's work it might be supposed that this gas completely absorbed all

[1] *Smithsonian Contributions*, No. 1413.

wave-lengths shorter than a certain value; from the present investigation, however, it will appear that the absorption is in the form of a band.

In addition to this feature oxygen presents an interesting contrast to the optical behavior of the other elementary gases investigated. For while hydrogen, argon, and helium seem all perfectly transparent in columns about a centimeter in length at atmospheric pressure, and while the absorption of nitrogen is very small, the absorption of oxygen is extremely strong. This fact taken in conjunction with considerations based on known photo-chemical phenomena suggested to the writer that the mechanism of absorption in the case of oxygen might be different from that which conditions the optical behavior of the other gases just mentioned. Some experiments have accordingly been made on the ozonizing effect of light, with the idea of extending the researches of Lenard and others into the region of extremely short wave-lengths. The outcome of these experiments is quite striking, for it appears that the ozonizing power of light increases very rapidly with decrease in wave-length beyond the point λ 1850. These results are of all the more interest since they appear to have some theoretical bearing on the behavior of the oxygen absorption band under change of pressure; the effect is very characteristic and consists in an unsymmetrical extension of the band. Now Larmor has predicted that, under certain conditions, such an unsymmetrical extension of the band will take place; the author's study of the formation of ozone seems to indicate that in the case of oxygen these conditions exist.

The band under consideration offers excellent opportunity for a test of Beer's Law. Work on this subject has already been undertaken and it is hoped that the results will form the substance of a future paper. The present measurements, however, are all concerned with absorption for a constant thickness.

As the absorbing action of oxygen offers a contrast to the behavior of the other simple gases investigated, so the behavior of its compounds—carbon monoxide and carbon dioxide—might be expected to show peculiarities. This expectation is borne out by experiment. The absorption spectrum of carbon monoxide consists of eight narrow bands, of a very striking appearance.

The practical result of the research relates to the nature of the absorption of air itself. The action seems to be conditioned entirely by the absorption of the oxygen with the slight absorption of nitrogen in the region near λ 1300 added to it. The effect of such quantities of ozone and water-vapor as exist in the atmosphere under normal conditions seem to be negligible.

It is greatly to be deplored that the opacity of fluorite limits the range of these experiments at a point in the spectrum considerably short of the present known limit, and in a region of special interest. Up to the present time, however, no substance more transparent than fluorite has been discovered.[1]

The following pages will contain a detailed account of the investigation.

APPARATUS

The apparatus is the same as that used in the measurement of the hydrogen spectrum,[2] except for the addition of the absorption chamber and for an improvement in the manner of attaching the discharge tube which served as a source of light.

The absorption chamber consisted of a vessel of glass 0.914 cm thick and 2 cm in diameter; it was provided with two ground flanges on which the windows of clear white fluorite were fastened with Khotinski cement. This chamber was attached to the inside of the face-plate of the vacuum receiver by means of the same cement. The outlet pipe of the chamber passed through a hole in the face-plate air-tight, and was connected to a mercury pump, a McLeod gauge, and the source of gas under investigation. Thus the arrangement was such that the light from the source passed through the absorption chamber before falling on the slit of the spectroscope.

The improvement in attaching the discharge tube was brought about by the employment of a brass collar *A* fitted with a screw thread. Into this collar the discharge tube was cast with Khotinski cement. The collar was then screwed into a cup *B*, which in turn screwed into a face-plate *C*.

The collar permitted the discharge tube to be removed without disturbing the rest of the apparatus. The cup allowed the use of an

[1] *Astrophysical Journal*, 25, 45, 1907.

[2] *Ibid.*, 23, 181, 1906.

extra fluorite window cemented in it, when so desired. In the absorption work no such extra window was used, since the chamber *D* fitted air-tight on the face-plate and served to separate the vacuum receiver from the discharge tube. This latter piece of apparatus was always separately exhausted. The alignment of the tube, which proved troublesome in the earlier investigation, was facilitated by boring the hole in the face-plate into which the cup screwed, at the proper angle. The final adjustment was made when the tube was cemented into the collar. Fig. 1 shows the detail of the arrangement. The relation of the discharge tube to the rest of the apparatus is shown in Figs. 5 and 7 of a former article.[1]

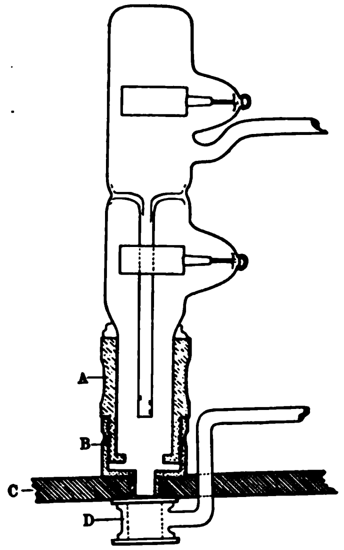


FIG. 1

It is well to note that there are three separate pumping systems in use with the apparatus, one for the vacuum receiver, one for the absorption chamber, and one for the discharge tube.

For the best results in absorption experiments a source should be used possessing a continuous spectrum, throughout which energy is equally distributed. In the region of very short wave-lengths such a source is not available. The nearest approximation to the desired condition is obtained by employing a discharge-tube filled with hydrogen containing a trace of carbon monoxide. This gas mixture gives a spectrum rich in lines and of fairly uniform intensity extending from λ 1850 to λ 1250. In practice, the discharge tube was washed with hydrogen until the visible spectrum showed that the gas was of the requisite constitution, the tube was then shut off from the pump, and the discharge was run through it for a sufficient length of time to insure its constancy during the experiment which was to follow.

The electrical excitation was furnished by the commercial trans-

[1] *Astrophysical Journal*, 23, 181, 1906.

former described in an earlier paper. No capacity beyond that furnished by the connecting wires was introduced. In measuring the current through the tube the author has had the advantage of Professor G. W. Pierce's apparatus.[1] This current, which was of course kept as nearly constant as possible throughout the experiment, proved to have a value of about ten milliamperes. The pressure in the tube was usually about one mm. The time of exposure, which was constant for any set of measurements, was usually five minutes. The slit of the spectroscope was rather wide, namely, about 0.09 mm.

It is to be noted that the light suffers absorption, not only in the chamber itself, but in the body of the spectroscope, since it must pass over a distance of about two meters in going from the slit to the photographic plate. For good results, therefore, it is necessary that the vacuum receiver should be very free from leaks and should be carefully washed with hydrogen before the experiment begins. Under these conditions, with a gas such as oxygen in the absorption chamber, the absorption in the spectroscope itself, which contains only hydrogen, can be neglected. But with more transparent gases absorption in the spectroscope must not be lost sight of if plates obtained under varying conditions of leak are to be compared.

The manner of making the experiment was usually as follows. The absorption chamber was exhausted to a pressure of 0.02 mm or less and an exposure made. The spectrum thus recorded showed only the absorption due to the gas in the body of the spectroscope. The gas under examination was then let into the absorption chamber until the pressure, as read by the gauge, reached the desired value. A photograph of the spectrum was then taken. The pressure was again changed and another spectrum obtained; and this process was repeated until a number of spectra were recorded sufficient to cover the photographic plate, each spectrum corresponding to a different pressure in the absorption chamber. The manner in which a number of exposures can be made on one photographic plate without opening the vacuum receiver is described in a former article.

It is important to remember that, if the absorption of a gas under different pressures is to be accurately observed, it is absolutely necessary that the required spectra should be recorded on one and the

[1] *Physical Review*, 25, 31, 1907.

same plate, for with the photographic emulsion which must be used in this spectral region[1] there is sometimes considerable variation in sensitiveness, even among plates which have been made at the same time. During any one experiment great care was taken to keep the conditions in the vacuum receiver and in the discharge tube constant. To this end after the receiver had been sufficiently washed with hydrogen the pump was kept continually in action to counteract the effect of any small leak; and the appearance of the discharge tube was constantly watched with a direct-vision spectroscope.

The pressure in the spectroscope when the experiment was in progress was of the order of 0.1 mm, and the maximum leak under which satisfactory work could be done was about 0.04 mm per hour. These conditions are much more difficult to obtain than those which suffice when a single emission spectrum is under investigation, for in the latter case, as the experiment is quickly finished, continual washings of hydrogen may be made to neutralize the effect of a very much larger leak than that mentioned above.

HYDROGEN

The absorption of this substance is stated by Schumann to be extremely small, but owing to the difficulty of producing a thick layer of the pure gas he obtained some contradictory results when working with long gas-paths.[2]

The author's data on the subject are in good agreement with these facts. The gas was prepared electrolytically from a solution of barium hydrate and dried over phosporous pentoxide. When used in the absorption chamber 0.91 cm long at a pressure of one atmosphere, it exercised no observable absorption.

An attempt was made to study its behavior in long columns by introducing it into the spectroscope itself; in this case the path was about 200 cm. Here the gas was prepared from zinc of great purity and hydrochloric acid, and was as before carefully dried by phosphorous pentoxide. Spectra taken through this gas at pressures of one to five cm show an absorption band near λ 1700, which, as it decreases with successive changes in the gas filling, evidently is due to

[1] V. Schumann, *Annalen der Physik*, 5, 349, 1901.

[2] *Smithsonian Contributions*, No. 1413, p. 18.

some impurity.[1] This contamination of the gas is probably due to the brass of which the spectroscope is made, since all connecting tubes are of glass. The weak spot in the spectrum between λ 1300 and λ 1330[2] is observed with the lowest pressures in the receiver and is always present. It is impossible to say whether this is a true absorption band for hydrogen or if it is a characteristic of the emission spectrum of the source of light itself.

At pressures near one atmosphere the absorption is considerable, the end of the spectrum being in the neighborhood of λ 1600. Here again it is impossible to say whether this action is a property of hydrogen or whether it is due to the presence of some impurity. A small trace of oxygen, for example, would account for the result. To make the experiment conclusive, it would be necessary to work with a spectroscope which could be made chemically clean. This condition would be very difficult to fulfil. The author hopes, however, to make some experiments on this subject with long columns of the gas placed in front of the slit of the instrument.

HELIUM

The author is indebted for the specimen of helium with which the work was done to the kindness of Professor E. P. Adams. In thicknesses of 0.91 cm, at atmospheric pressure, the gas shows no observable absorption in any part of the spectrum between λ 1900 and λ 1250.

ARGON

The gas was obtained from atmospheric nitrogen. I am indebted to Professor Baxter for his kindness in superintending the preparation. The gas showed a very slight trace of hydrogen in the visible spectrum. In columns of 0.91 cm it produced no observable absorption in any part of the spectrum, even when at atmospheric pressure.

NITROGEN

The gas was atmospheric nitrogen prepared in the usual way by passing air over hot copper and, like all the other gases, carefully dried.

In columns of 0.91 cm and at atmospheric pressure the gas pro-

[1] *Astrophysical Journal*, 19, 265, 1904.

[2] *Ibid.*, 23, 181, 1906.

duces a very slight absorption extending continuously from λ 1800 or thereabouts to λ 1250. The strength of this absorption increases slightly but regularly with decrease in wave-length, but even at the most refrangible end of the spectrum it is very small indeed.

It is interesting to note at this point that, as argon is perfectly transparent and as nitrogen is not, the matter of absorption is probably not simply connected with increasing atomic weight.

Schumann remarks: "Nitrogen proved itself very transparent even beyond $162\mu\mu$, yet it absorbed particular wave-lengths very energetically."[1] The author has been unable to observe this absorption of particular wave-lengths in the region between λ 1900 and λ 1250.

Experiments on this gas with greater lengths of path would be of interest.

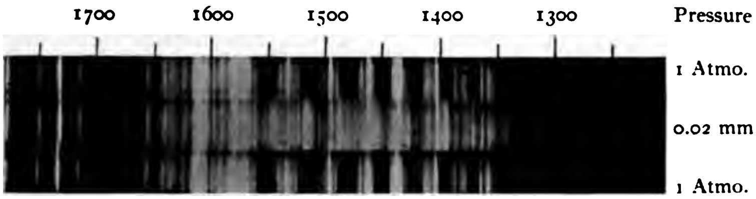
OXYGEN

The behavior of this substance affords a strong contrast to that of hydrogen, helium, argon, and nitrogen, for it absorbs light of short wave-lengths most energetically. This fact was discovered by Schumann. The present research marks a considerable advance in our knowledge of the properties of this gas, however, since from the writer's results it now appears that the absorption of oxygen is in the form of a band. This fact is entirely new.

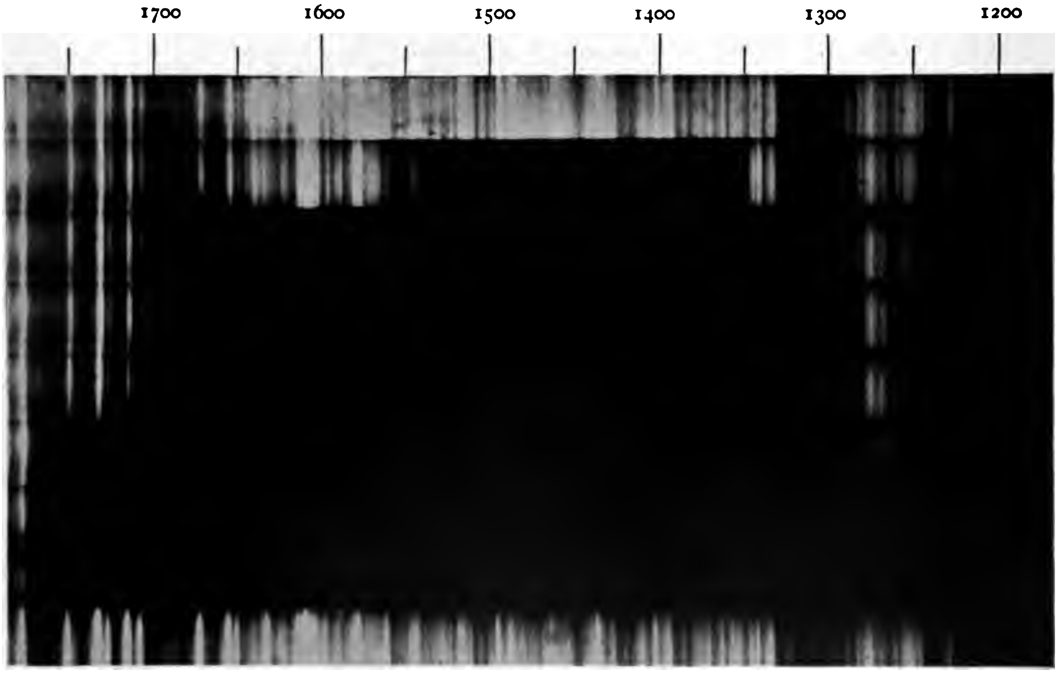
The gas was prepared electrolytically, heated to destroy ozone, and carefully dried over phosphorous pentoxide. It was then introduced into the absorption chamber and experiments on the relation of absorption to pressure were made upon it in the manner previously described. The result is shown in Plate VII. The character of the band is unmistakable. With a pressure of one atmosphere, the more refrangible limit is not visible in the reproduction, though it can be just made out in the plate itself, but as the pressure in the absorption chamber is decreased this limit comes into view. Most unfortunately a careful study of the more refrangible region is much interfered with by the absorption of the fluorite windows, which first begins to be noticeable near λ 1300. There does seem to be, however, some indication that another absorption band exists, lying in the region

[1] *Smithsonian Contributions*, No. 1413, p. 15.

PLATE VII



The Absorption of Carbon Monoxide



The Absorption Band in Oxygen

Beginning at second strip from top, the pressures are 0.02, 0.05, 0.07, 0.10, 0.25, 0.5, 1.0 atmospheres

shut out by the opacity of the fluorite. Nothing definite can be said on the subject and attention will, therefore, be directed chiefly to the phenomena as shown in the strong band.

The mere existence of this band is an important fact, but it is not the only result which the experiment yields. A glance at the plate is enough to show that the width of the band changes with pressure in a characteristic manner. For as the pressure increases the absorp-

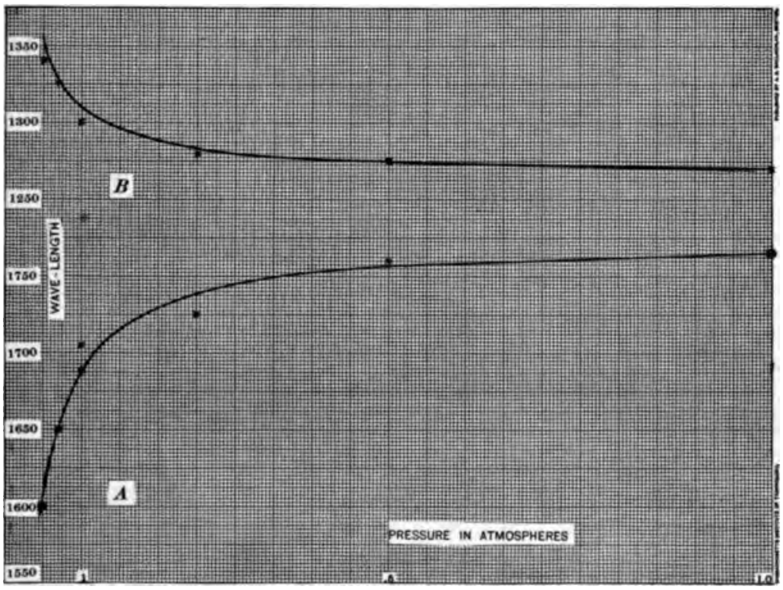


FIG. 2

tion spreads much more rapidly toward the less refrangible side than in the other direction. This action is shown graphically in Fig. 2, where the last visible wave-length is plotted against the corresponding pressure. *A* is for the less refrangible end of the band, *B* for the more refrangible limit. When it is considered that the emission spectrum is not continuous and not perfectly uniform, it is surprising how closely the points lie on the curves. It is not difficult to find empirical equations to fit the curve. For *A*, the equation takes the form

$$(\lambda_0-\lambda)p=c,$$

where λ_0 and c are constants having the values 1773 and 8.6 respectively; and B can be expressed by the relation

$$(\lambda-\lambda_0')p=D,$$

where λ_0' and D have the values 1266 and 4.5. In order to show how close the fit is, the observed points are marked with crosses and the curve is drawn through the calculated values. The agreement is fairly good, but too much weight must not be put upon it; for though the relation between the pressure and the minimum energy at the given point in the spectrum necessary to affect the photographic plate affords most alluring material for theoretical speculation, the uncertainties of the experiment make any general conclusions founded on numerical data of rather dubious value. The unequal and unknown distribution of energy in the spectrum, the possible change of sensitiveness of the photographic plate with change in wave-length, and the absorption by the fluorite windows introduce such complications into the case that any very exact relation such as that shown by the curves would seem to rest on some happy accident rather than on any fundamental principle.

Though exact numerical results cannot be expected to follow from the experiment under consideration, yet some interesting general conclusions may be deduced from the data at hand.

Unsymmetrical bands in the case of gaseous absorption are by no means unknown. Such a band exists in chlorine, as has been shown by Miss Laird,[1] and more recently Wood[2] has investigated absorption of this kind in mercury vapor. Bands of this type are of special interest.

Planck, in his work on the optical properties of gases, predicts for cases of very strong absorption the existence of bands which with change in pressure widen more rapidly on their less refrangible side than at their more refrangible limit; in addition his theory calls for an actual shift of the maximum of absorption with pressure change. Unfortunately, as Kayser has pointed out, it is almost impossible to tell by any method whether the movements of the edges of the band are real or apparent.

[1] *Astrophysical Journal*, 14, 114, 1901.

[2] *Ibid.*, 26, 41, 1907.

The theory of Larmor,[1] which has some application to Wood's observations of mercury, seems to have a more direct physical meaning in the present case, though we are still in the presence of the difficulties to which Kayser has called attention. Professor Larmor ascribes the unsymmetrical nature of the band in mercury to the formation of loose aggregates of molecules. He says: "The molecules in such loose aggregates would, owing to their (slight) mutual influence, vibrate in longer periods, and give rise to the displaced part of the band." Thus if the hypothesis is to have an application to the case of oxygen it will be necessary to show that the formation of such aggregates is not impossible in this gas.

With this idea in mind, it is at once remembered that oxygen stands out among the elementary gases investigated because of its extremely strong absorption. It is not unnatural to inquire, then, if the mechanism of absorption in oxygen is the same as in other gases. Granted for the moment that in hydrogen, argon, and helium such energy as is absorbed is dissipated in some kind of friction operating on the vibrating system, or, according to Planck, in radiation given out again by the system, can we conceive of still other agents which will transform energy in the case of oxygen and by which its extremely high absorption can be explained? Long ago Helmholtz[2] pointed out that such agents probably exist. "Die starke Absorption ist also von starkem Mitschwingen der Molekeln begleitet, so dass wir dabei auch Wärmeentwickelung und unter Umständen ein Zerreissen der Ionenverbindungen erwarten können, namentlich wenn noch eine elektrostatische Ladung der Substanz hinzukommt. So sind wohl die Beobachtungen von Hertz zu erklären über die Entweichung der Elektricität unter den Einfluss der ultravioletten Strahlen."

The action observed by Hertz is now believed to be due to the action of light upon a solid rather than upon a gas; the passage is quoted, however, as it suggests directly the nature of the agents by whose action the absorption of oxygen is distinguished from that of other simple gases. These agents are ionization, and the formation of ozone or hydrogen peroxide.

On the subject of the ionization produced by ultra-violet light,

[1] *Astrophysical Journal*, 26, 120, 1907.

[2] *Vorlesungen*, Band V, 342.

we have the work of Lenard.[1] Lately an observation has been carried on in this laboratory which corroborates the results obtained by the earlier observers and which, it is hoped, will throw light on the question of the relation of ionization to wave-length. The work is not yet finished, but it may be stated with certainty that volume ionization is produced to a considerable extent by light of such wave-lengths as we are concerned with in the present investigation.

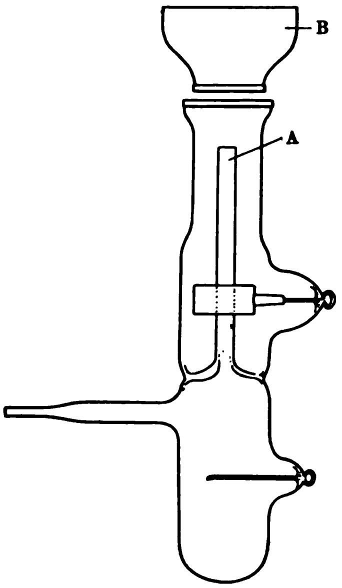


FIG. 3

On the question of chemical action produced by ultra-violet light, there is considerable data at hand. Most of the investigators, however, including Lenard, have limited themselves to light less refrangible than that of wave-length λ 1800, and in the case of those who have probably used a shorter wave-length there was no means of determining the exact position in the spectrum of the vibrations which yielded the results. The writer has, therefore, undertaken some simple experiments on the subject, which, as they have to do with the question in hand, will be described here.

A discharge tube of the internal capillary type, Fig. 3, was filled with hydrogen to about one mm pressure and closed by a fluorite window. The tube was excited by the transformer previously mentioned; there was no capacity in circuit. The current was of the order of ten milliamperes. Under these conditions the gas showed the many-line spectrum of hydrogen. The following experiments were then tried:

1. Half of the fluorite window was protected by a piece of microscope cover glass and over it was laid a bit of paper moistened with starch paste containing potassium iodide; in fifteen seconds the paper turned strongly blue where it was not protected by the glass, the protected portion remaining perfectly unaltered.

[1] *Annalen der Physik*, 1, 486, 1900.

2. A piece of quartz two mm thick was next placed on the fluorite window so as completely to cover it; the test paper was placed on the quartz. In fifteen seconds there was a noticeable discoloration of the paper, but the effect was not nearly so well marked as in case 1.

3. A shallow vessel *B* with a fluorite bottom was next placed directly upon the discharge tube so that the two fluorite plates were in contact. The test papers placed within this vessel upon the fluorite bottom showed in fifteen seconds a discoloration only slightly less than that observed in case 1.

4. The vessel *B* was now raised one-half mm above the window of the tube; thus the light was forced to penetrate a column of air one-half mm thick in addition to the fluorite plates; the discoloration of the paper in fifteen seconds was now very slight.

5. If the vessel was removed to a distance of one mm, no discoloration could be observed. It is evident that the agency which produces the discoloration is weakened by quartz and is, so far as these experiments show, entirely cut off by one mm of air. There can be but little doubt that the agency is light of a shorter wave-length than λ 1850.

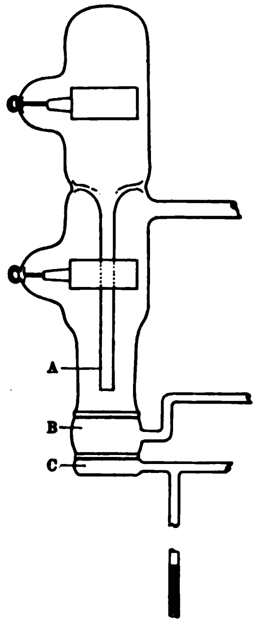


FIG. 4

A more elaborate experiment was next undertaken. A discharge tube had cemented upon its fluorite window a chamber *B*, 0.7 cm thick; this chamber in turn was closed by a fluorite window which carried a second shallow vessel *C*, 0.1 cm thick. This last vessel was connected to a manometer column which dipped in strong sulphuric acid. The function of the chamber *B* was to serve as a screen of variable transparency, and to this end it was connected to a mercury pump and McLeod gauge. The discharge tube was filled with hydrogen at about one mm pressure. The vessel *C* was filled with oxygen at atmospheric pressure. No change in the manometer column was observed when the discharge tube was excited. It was only when the pressure in *B* had been reduced to about one cm that the acid in

the manometer column began to rise, but this rise continued to increase as the pressure in *B* was reduced step by step. Care was taken to correct as far as possible from heat effects.

The results with this more complex apparatus are only of a preliminary character. They serve to corroborate the results of the simpler experiment. There seems to be no doubt that light of wave-lengths shorter than λ 1850 acts to produce chemical action energetically, and that this action increases considerably in strength with decrease in wave-length in the region more refrangible than λ 1850.

That ultra-violet light produces ozone is a very well-known fact, but the writer believes that the action of such a feeble source of light as a hydrogen tube in producing change in the gas around it has not before been observed. The connection between the magnitude of this change and the wave-length of light has probably also not been recorded, at least for the spectral region under discussion. It must be remarked, however, that the starch-paper test cannot distinguish any more than the manometer between the production of ozone and hydrogen peroxide. The gas formed may be either the one or the other.

The whole question of the relation of wave-length to the velocity of chemical reactions which are affected by light is one of extreme interest. A research on this subject is now in progress in this laboratory.

We may now return to Larmor's theory of the unsymmetrical broadening of the oxygen band. It is evident that the required molecular aggregates are furnished either by ionization or by the products of chemical action, or more probably by both agencies working together. If, therefore, the apparent shift of the limit of the band is in fact a real shift, the theory of Larmor has received corroboration at the hands of the oxygen band.

An investigation of the behavior of the band in chlorine or in mercury vapor under pressure change might yield interesting results; the writer hopes to turn his attention to the matter at some later time.

In conclusion it is important to inquire what the optical properties of ozone are in the region under examination, for it seems very probable that this substance is formed in oxygen during the process of absorption. Schumann states: "The presence of a moderate

amount of ozone does not alter the absorption at all." The writer's experiments bear out this conclusion. Ozone was made by the action of the silent discharge; it was then run over phosphorous pentoxide and introduced into the absorption chamber. No difference could be noted between the absorption of pure oxygen and that produced by oxygen containing ozone.

The absorption in oxygen therefore, though it is closely connected with the production of ozone, does not seem to be affected by the presence of the gas when produced from another source.

So far all the results which have come under discussion were obtained by varying the pressure with a fixed thickness of gas. The oxygen band, however, offers a good opportunity for a test of Beer's Law, and the writer hopes to collect data similar to those here presented, but for various path lengths, at some future time. The work, however, is tedious and the inherent difficulties of such experiments will probably cause some delay.

Schumann has observed fourteen groups of absorption lines near λ 1850 which he attributes to the action of oxygen. He says: "These groups which are of bandlike form constantly approach nearer one another with their deviation and are shaded off toward the red. Complete absorption is to be found with the most refrangible of them."

The writer has never been able to get satisfactory photographic records of this phenomenon, perhaps because of the difficulty he has experienced in obtaining a continuous spectrum of any strength in the neighborhood of λ 1850 and because the slit of his spectroscope falls short in perfection of the extremely beautiful instrument used by Schumann.

It must be noted that these groups exist at the less refrangible end of the great absorption band. Judged in relation to it, they are probably of a feeble character.

CARBON DIOXIDE

The gas was prepared by heating sodium bicarbonate, and was dried over phosphorous pentoxide. The absorbing action is similar to that of oxygen, but much less energetic. Thus at one atmosphere pressure the last visible wave-length with oxygen is λ 1760, while with carbon dioxide it lies near λ 1600. The relation of least visible

wave-length to pressure resembles that found in oxygen, but the curve which shows the results is far less smooth than in the case of the simpler gas. There is considerable probability that this effect is produced by maxima and minima which occur throughout the band; in fact, some of the minima are clearly evident when the absorption of the gas is observed at low pressures. They occur in the region between λ 1600 and λ 1300. Schumann has observed similar narrow bands at the less refrangible end of the region.

Unlike oxygen, the more refrangible limit of the band has not been discovered, perhaps because it lies in the region shut off by the opacity of fluorite.

CARBON MONOXIDE

The gas was prepared from oxalic and sulphuric acids and dried as usual.

The absorption is very characteristic and quite unlike that of oxygen, as may be seen from Plate VII. There seems to be very little action from λ 1850 to λ 1600, but from λ 1650 to λ 1250 eight separate bands exist. The maxima occur near λ 1548, 1512, 1482, 1450, 1423, 1395, 1370, 1345. For any given pressure they decrease in width with decrease in wave-length. As the pressure is reduced, each band contracts, but even at a value of 0.1 of an atmosphere, all the bands are still distinguishable. They do not correspond to any lines or groups of lines in the emission spectrum of the gas. At least two of the bands seem to coincide with those observed in carbon dioxide. The limit of the spectrum as shown in the illustration is not due to absorption but to the character of the source of light.

Schumann speaks of carbon monoxide as producing "a series of rhythmical inverted groups of lines." As he confined his attention almost entirely to the part of the spectrum on the less refrangible side of λ 1600 it is probable that this group of lines does not coincide with the bands which are illustrated in the accompanying plate and which lie in the region below this limit. As in the case of oxygen the writer has been unable to obtain any satisfactory data as to the existence of the less refrangible minima.

The absorption of carbon monoxide, so different from that of any of the other gases so far investigated, deserves further study. Like all the experiments described in this paper, the results were obtained

for a single gas thickness of 0.91 cm. Longer gas paths should yield interesting data.

AIR

The absorption of the air is one of the most important factors in all practical problems relating to the region of short wave-lengths, and direct experiments were, therefore, made on the subject even before the work on the elementary gases was begun; exactly the same method being followed in making observations on the effect of change of pressure as was employed later with other gases.

It appears that the absorption of carefully dried air can be described as due to the absorptions of the oxygen and nitrogen which it contains. As might be expected, it is more transparent than oxygen, for, while with oxygen at atmospheric pressure and a path of 0.91 cm the last visible wave-length is near λ 1760, for air under similar circumstances it is near λ 1710. Moreover, in air as in oxygen the absorption is in the form of a band. There is one difference to be observed, however, between the action of the gas mixture and that of the element, for with air the more refrangible end of the band is rather indistinct, while with oxygen at a corresponding pressure it is extremely sharp. This effect is probably due to the presence of nitrogen whose absorption, though very slight, is yet enough in the region of shortest wave-lengths to account for the result. It seems improbable that such traces of ozone, carbon monoxide, and carbon dioxide as are ordinarily to be found in the atmosphere can have any marked effect upon its absorption for that part of the spectrum which has been considered in this paper. Moreover, from experiments on dry and moist air, the effect of such quantities of water vapor as occur in the air of a laboratory seem to be negligible, at least within the limits of these experiments.

It must be remembered, however, that in treating the absorption of the atmosphere for light less refrangible than λ 1900, these statements may not be true. Ozone, for example, is known to exercise strong absorption in the region between λ 3000 and λ 2000; in fact, the limit of the solar spectrum has been ascribed by Hartley and others to its presence in the atmosphere. It seems not improbable, therefore, that the agents which determine the opacity of the air for light of greater wave-length than λ 2000 may be somewhat different

in nature from those whose action produces the absorption of light of wave-lengths more refrangible than this value.

Finally, it is of considerable interest to inquire what inference may be drawn from the data at hand as to the transparency of the air for light of even shorter wave-length than that which is recorded on these plates. For it is obvious that if it could be shown that the air is transparent to ether vibrations of very high frequency the result would be of considerable importance.

Unfortunately, nothing very definite can be said on the subject. The fact that the ultra-violet limit of the absorption band in oxygen appears to spread in both directions with decrease in pressure points to the existence of a second region of absorption beyond the point at which fluorite becomes opaque. Moreover, as far as the data now at hand are concerned the absorption of nitrogen seems to increase rather regularly with decrease in wave-length. These facts taken together would indicate that no great improvement in the transparency of the air for light more refrangible than λ 1250 is to be expected. On the other hand, since the limits of one oxygen band have been discovered, it seems not improbable that if a second band exists, it too will have its end; moreover, it is perhaps legitimate to surmise that the absorption of nitrogen is in the form of a band and that for very short wave-lengths this gas also may regain its transparency.

In short, though it seems improbable that the air is transparent for light of the very shortest wave-length, yet the results of this research indicate that such a state of things is not impossible.

CONCLUSIONS

1. The absorption of hydrogen, argon, helium, nitrogen, oxygen, carbon monoxide, and carbon dioxide has been investigated for a single thickness, but with varying pressure, between λ 1850 and λ 1250.

2. Hydrogen, argon, and helium in thicknesses of 0.91 cm and at atmospheric pressure produce no observable absorption in this region.

3. The absorption of nitrogen, though slight, is perfectly perceptible even for a thickness of 0.91 cm. The absorption appears to increase with decrease in wave-length.

4. The absorption of oxygen takes the form of a band extending,

if the thickness is 0.91 cm and the pressure is atmospheric, from near λ 1760 to near λ 1270. The behavior of this band with change in pressure has been studied. The mechanism of the absorption of oxygen as distinguished from that in other gases has been discussed and some new experiments on the effect of light of very short wave-length in producing chemical change have been tried. The results have been found to bear upon a theory of the unsymmetrical shift of the limits of absorption.

5. The absorption of carbon monoxide has been found to be unlike that produced by oxygen, in that it is characterized not by one broad band, but by eight narrow bands in the region between λ 1600 and λ 1250.

6. The absorption of carbon dioxide is characterized by the presence of a broad band slightly resembling that due to oxygen, but complicated by the presence of maxima and minima within its limits.

7. The absorption of the air for the region between λ 1850 and λ 1250 appears to be due to the combined actions of the oxygen and nitrogen which it contains. Under the conditions of this research, in thickness of 0.91 cm and at the pressure of one atmosphere the last visible wave-length lies in the neighborhood of λ 1710. As in the case of oxygen the absorption is in the form of a band.

JEFFERSON PHYSICAL LABORATORY
HARVARD UNIVERSITY
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THE FUNCTION OF A COLOR-FILTER AND "ISOCHROMATIC" PLATE IN ASTRONOMICAL PHOTOGRAPHY

By ROBERT JAMES WALLACE

The new era in photographic science, opened by the introduction of the (so-called) isochromatic plate and its accompanying color-filter, was pregnant with significance to astronomers in general throughout the world, for that hitherto while the application of photography to the recording of results could be attained only by the possession of an expensive correcting lens, the simple combination of a color-filter and isochromatic plate not only fulfilled all requirements, but did so more perfectly.

It requires but little consideration to arrive at the very logical conclusion that, whether an individual be equipped with but rudimentary photographic knowledge or an extended experience, successful results are more or less a matter of "accidentals." Natural causes compel that this must be so, i. e., the unsteadiness of the earth's atmosphere, and consequent "bad seeing." Every astronomer knows that during the period of an observation there are moments when the image appears to "steady down" and detail "flashes out," only to be again lost in the ensuing "boiling." In the case of a large image like the moon, these moments of steadiness can be watched for and taken advantage of when they occur; but, naturally, it is the exposure of plate after plate, or, the exposure of portion after portion of the same plate, that gives results; because it is obvious that, given even fairly good seeing, the development of a large number of exposures taken consecutively throughout the period must result in some that are much better than others, since the better ones utilize the light during a momentary steadiness. It follows, therefore, that the steadier the air the greater the percentage of good images, and the greater the number of exposures the better the chance for success.

Assuming the possession of a telescope and camera-box, together with a plentiful supply of plates and a modicum of manipulative photographic knowledge (which is not synonymous with a knowledge of photography), there are but few things less difficult than obtaining

results in so far as the operator is concerned; the only element of uncertainty introduced being the atmospheric disturbances, over which he has absolutely no shadow of control. The focus is fixed by star-trails at any time prior to the exposure, and once determined it remains constant except for temperature, which by contraction or expansion of the metal parts of the telescope, or change of figure in the objective, shifts the focal plane nearer to or farther from the objective. Several settings, however, at varying temperatures provide points upon which is erected a focal curve, the casual observation of which, before or during work, instantly indicates the exact focal setting.

It is an almost incomprehensible fact that while the principles underlying the use of color-filters and "isochromatic" plates are very thoroughly understood by all students of photography, yet in astronomical circles generally the most vague and visionary ideas are entertained, and this too, in many cases, by the very individuals who are making constant use of both. It is unfortunate that the data relative to the subject is almost wholly scattered throughout the photographic and other journals (mostly European), and so much has been written by so many people, that to attempt the compilation and necessary editing of the material would be a task truly herculean. The purpose of the present paper, therefore, is an attempt to set forth connectedly the principles governing their use.

In the adjustment of a color-filter to a visual refracting telescope the point of first consideration is the correction of the lens for color, i. e., the "color-curve." Generally speaking, the region from λ 5400–λ 5900 represents the portion most nearly flat, viz., where the rays approximately come to the same focus, while the focal points of different wave-lengths lie at a gradually increasing distance apart. As a typical example of a visually corrected Clark objective, the color curve for the 40-inch telescope is shown in Fig. 1.

If all light-rays passing through the objective were to come to a focus at the same plane, then of course the color curve would be represented as *f*, and when photography was attempted it would simply be sufficient to place in that plane a photographic plate whose selective sensitiveness it would not be necessary to consider.

Strictly speaking, there is only one point upon the curve which is

directly coincident with *f*; but generally speaking, and in practical consideration, a much greater extent is permissible, this extent being limited by the diameter of the confusion circles, which are themselves dependent upon the angle subtended by the objective.

In the case of the 40-inch telescope the angle subtended at the visual focus equals almost 3°. Considering the light-ray at λ 5650

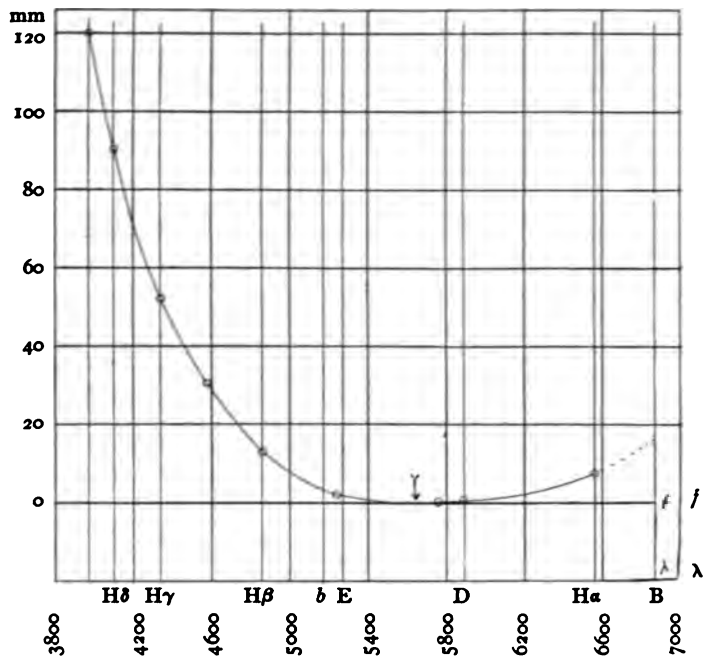


FIG. 1.

(indicated on the figure by an arrow) as forming a point source at the plane of the plate at *f*, it will be seen that the different focus points of different wave-lengths will be spread out into confusion circles of greater or less diameter as the rays cross nearer to or farther from that plane. Light, therefore, of λ 4800 and λ 6700 will be spread out from a point source into a circle whose diameter equals about 0.7 mm. As the intensity of the light is diminished in inverse proportion to the surface, it follows then that a light-intensity of unit value at its focal point must possess a weakened photo-chemical value according to the distance the plate is removed from that focal point. Hence it

cannot produce the same effect upon a photographic film unless the time of exposure be proportionately extended, such extension from investigations by Abney,[1] Schwarzschild,[2] Mees and Sheppard,[3] and others, being represented as $I \times t^p$ the value of the exponent[4] being less than unity, and varying with different plates. In all probability it also varies with the wave-length.[5]

The value or amount of this weakening of the light is, however, dependent upon another factor, and *that* a most important one, viz., the sensitiveness of the plate to the wave-length in question. The portion of the color curve which approximates a straight line lies in the very region to which the ordinary photographic film is entirely insensitive, and hence enters the isochromatic plate.

It is an interesting coincidence that it is just thirty-four years ago this month that the first publication was made in English of Dr. H. W. Vogel's discovery on photographic sensitiveness to rays of longer wave-length than the blue, by the introduction to the emulsion of sundry dyestuffs and also the first use of a color-filter. Vogel's original announcement was made just one month prior. It does at first sight appear somewhat strange that, in spite of the almost immediate and since continued activity of the plate-manufacturer, the commercial "iso" or orthochromatic plate of today is practically but a very slight advance upon the primary discovery. It is nevertheless a disagreeable fact.

The difference in selective sensitiveness between the ordinary and the isochromatic is plainly shown in Fig. 2, which illustrates graphically the sensitiveness curves of a Seed "27" and a Cramer "Instantaneous Isochromatic."

It will be noticed that the "iso" plate possesses a secondary maximum at about λ 5600, which is approximately even in intensity from λ 5300 to λ 5700, a most convenient coincidence, as this region corresponds precisely with the flat portion of the objective color curve.

[1] *Proc. Roy. Soc.*, 54, 143, 1893.

[2] *Astrophysical Journal*, 11, 89, 1900.

[3] *Theory of the Photographic Process*, p. 214.

[4] Where I = intensity, and t = time of exposure.

[5] A. Becker and A. Werner, "Das photographische Reziprozitätsgesetz für Bromsilbergelatin bei Erregung mit Licht verschiedener Wellenlänge," *Zeitschrift für wissenschaftliche Photographie*, 5, 382, 1907.

It results therefore that if the isochromatic plate be placed in the plane of *f*, the secondary sensitiveness of the plate and the focus for the yellow-green rays are coincident. It is of course true that all of the wave-lengths between say λ 5200 and λ 5900 do not come to *precisely* the same focus, but they do so with practical identity.

The strong maximum at the blue end of the isochromatic plate is an unfortunate condition which up to the present has not been sus-

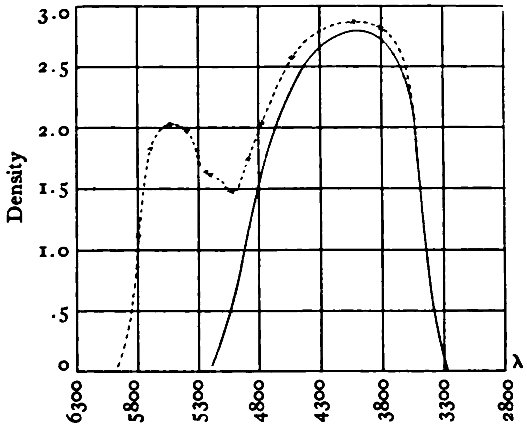


Fig. 2

ceptible of much improvement. It does not exist from lack of effort to remove it, because both the plate-manufacturer and the independent investigator have devoted much time to its subjection, but without satisfactory results; for while it has been possible to lower it by the introduction to the film of otherwise inert dyes whose absorption corresponded with the blue maximum, yet it has been at the expense of speed, which is thereby greatly lowered. The Cramer "*slow* iso" is typical of such a plate.

It might at first thought be considered possible (and several astronomers have attempted) to make use of such a stained plate in astronomical photography; but it must be remembered that, although the sensitive film may be so loaded with dye as effectually to filter out the overactive blue-violet rays from the light transmitted by it, yet on the surface of the film the particles of silver bromide are covered with a layer of dye of extreme attenuation; hence there would always

be action by the blue-violet light although in a lessened degree, which would result more or less in submergence of the sharp image under a veil of confused out-of-focus light of comparatively great actinic energy. The out-of-focus red light at the other end of the curve need not be considered, as the plate is insensitive to radiations of this wave-length, even with very prolonged exposure. The only practical method for the elimination of this out-of-focus blue-violet light is by the employment of a color-filter which will absorb it before reaching the sensitive film. It is axiomatic that pure monochromatic light acting upon the plate will produce the sharpest image.

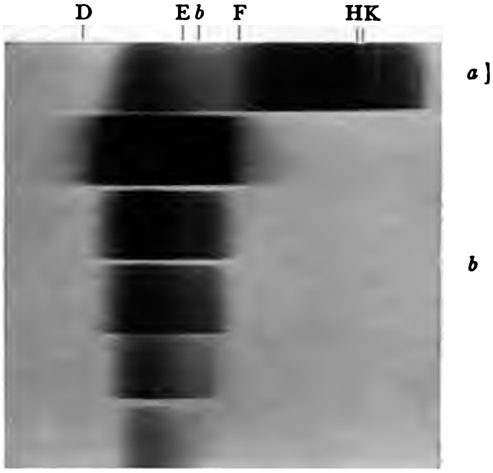


FIG. 3.—*a*. Cramer instantaneous isochromatic unscreened. *b*. Cramer isochromatic, increasing exposures through color-filter.

Not only is it impossible to construct color-filters to transmit true monochromatic light, but even if it were possible they would be valueless, because the light transmitted would be too feeble to be effective. They are constructed, therefore, to absorb all wave-lengths shorter than from about λ 4600 to λ 5400, depending upon the class of work for which they are to be used. It is necessary, generally speaking, to have a color-filter with a closer approximation to monochromatism when engaged in the photography of faint detail. This is a point well understood by all experienced photographers, and approximate monochromatic light-filters in photomicroscopy have been used a greater number of years than I would care to go on record as quoting. Such filters have also, for some time, been a regular article of commerce.

There is a great deal of uncertainty relative to the absorption of a certain color-filter, and it may as well be stated now that the photographic absorption of a color-filter, with a certain plate, depends upon the exposure which that plate receives. Increase of exposure

means increased extent of action. This is true of all filters (see Fig. 3).

The best position for the color-filter is immediately in front of the sensitive plate. In such position it is known that it displaces the image by a distance equal to $t\left(\frac{\mu-1}{\mu}\right)$ when t is the thickness, and μ refractive index; hence it is necessary, for this cause alone, to determine the position for a new filter, before exposure is made. For critical work it is necessary to determine focus separately for two color-filters, even should they possess practically the same absorption, because in manufacture, no matter what amount of care is used, small differences are unavoidable.

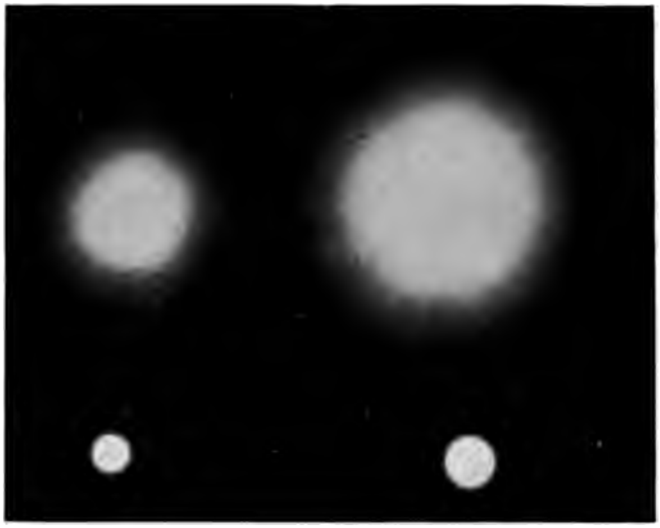
If the filters possess different absorptions, then it requires merely a primary knowledge of that and the objective's color curve, to know that the focus *must* necessarily be different.

In a paper by Dr. Schlesinger in the *Astrophysical Journal* of 1904 (**20**, 123) dealing with photographic star-images for parallax determination, an illustration is shown of a loose cluster taken with the 40-inch telescope, on an isochromatic plate, *without* the interposition of a color-screen. In this plate the enlargement is so slight—1.7 times—that the quality of the images cannot be shown. Besides, such an enlargement is in no wise comparable with that required in lunar or planetary work. A number of illustrations are therefore given (Figs. 4 and 5, Plate VIII) of series of exposures made at the 40-inch telescope upon the same star, both with and without a color-filter. The exposure times are 30 sec., 1 min. 30 sec., 4 min. 30 sec., and 13 min. 30 sec., and the enlargement is rigorously exact on each to eight diameters. The statement by Schlesinger that "careful comparison of stellar plates, taken with the screen and without, shows that there is little to choose between them, either as regards the minuteness of the images or their sharpness," cannot therefore be accepted. It should be said, however, that his comparisons were on negatives made by Ritchey with a color-filter which transmitted a considerable amount of blue light, extending almost to λ 4500; also, his statement applies particularly to faint stars, which in reality do present but little difference unless they be much enlarged.

During the period covered by the past fourteen years the writer

PLATE VIII

Fig 4



a

b

Fig. 5

a

b

Star Images with the 40-inch Telescope

(*a*) Without color-filter, and (*b*) with color-filter

Times of exposure equal for each pair

has given considerable time to the special study of absorption filters for various conditions, and in 1903–4 devoted much labor to the critical requirements necessary in filters for astronomical photography. Use was made of the 12-inch and 40-inch telescopes and about 500 lunar and stellar negatives were made at various times throughout that period. These negatives were made under all possible (logical) variations of the color-filter, both "liquid" and "dry," and of mean transmissions of from λ 4200 through many steps to λ 5500. Some of these filters also absorbed the red end of the spectrum. This large number of negatives contained some exceedingly choice images which were selected and their filters located in the laboratory notebook. Deductions from these results showed that with a range of 100 tenth-meters within the limits of λ 4700 or λ 4800 there was no certain improvement discernible on the delineation of detail when the exposures were at the minimum allowable for normal development, although, as has been stated, *theoretically* they should increase in value as the filter approaches monochromatism.

FIG. 6.—Spectral transmission of various color-filters.

Fig. 6 shows the transmission spectra of several of the color-filters used at this observatory, while Fig. 7, Plate IX, shows the difference between the images obtained with practically similar exposures by the use of filters λ 4600 and λ 4900 respectively. Between these two limits, there is noticeable a gradual increase in quality value of the images as they approach nearer to monochromatic conditions. The filter in most general use here possesses a mean absorption of λ 4900.

In the justly famed lunar negative made by Ritchey the densest color-filter used by him transmitted blue light as short as λ 4500, yet the seeing was so good, and the exposures were so successfully handled, that, from the comparatively small number made, he was enabled to select several that show a delicacy of detail which, although inferior to visual observations, has given them the premier place in photo-

graphic lunar delineation. Had the exposure been prolonged it would have been at the expense of definition—the summation effect of the action of the blue light and the atmospheric tremor.

In a recent paper by Professor Lowell there has been advanced what he terms a "new means of sharpening celestial photographic images," and the paper is illustrated by diagrams, to show the curves of color-sensitive plates, and of the Lowell objective respectively. The title is misleading, however, because fallacious, being founded upon a misconception of the theory.

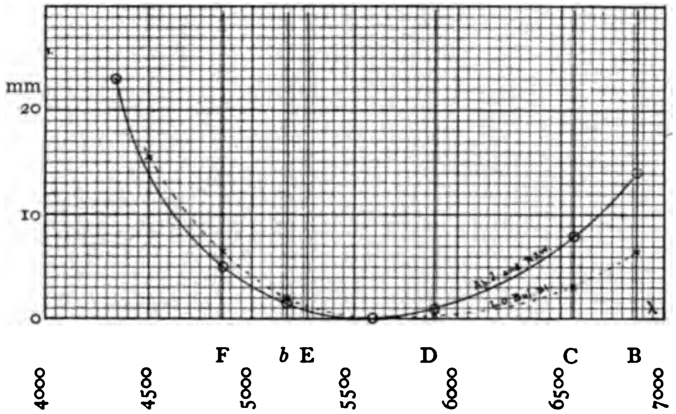


FIG. 8

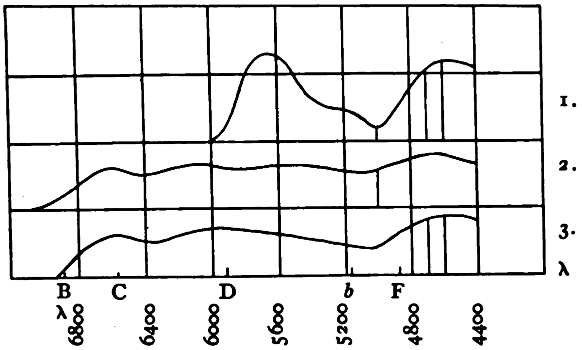
Briefly expressed, the "device" consists in sensitizing an isochromatic plate for the red, and making use of a color-filter with an absorption at λ 5000 (made by the writer). His first illustration shown represents the color curve of the Lowell 24-inch objective, but the curve shown by Lowell differs considerably from curves supplied me for the construction of his color-filters, and differs also from that published by Slipher in the *Astrophysical Journal.*[1] This lack of accordance is shown in the illustration (Fig. 8), where it will be seen that there is an ordinate difference of from 5 to 7½ units at the Fraunhofer C and B lines. A close search fails to find anything published regarding a redetermination of the curve later than that already published by Slipher.

[1] 20, 9, 1904.

The second illustration is entitled "curves of sensitiveness of photographic plates" (Fig. 9*a*), but as such they are unfortunately quite wrong.

Taking that one plotted as the "Cramer instantaneous isochromatic" and comparing it with the *actual* sensitiveness curve plotted from careful measurements as shown by the dotted line (Fig. 9*b*),

FIG. 9*a*



1. Cramer Instantaneous Isochromatic.
2. Seed "23": Pinacyanol and Pinaverdol bathed.
3. Seed "23": Pinacyanol and Pinachrome bathed.
(Ordinate values were not indicated.)

the result serves well to show the futility of plotting densities from visual estimates.

The two Lowell curves shown extending into the red beyond B, are marked respectively "Seed 23 bathed with pinacyanol and pinaverdol," and "Seed 23 bathed with pinacyanol and pinachrome." The context of the paper informs us that a trial of these two plates thus treated resulted in failure, the cause for which it is suggested may lie in the developer used. Inability in the present writer to follow the reasoning which prompts this suggestion, leads, however, to discarding the attempt, when it is obvious that the failure follows *inevitably* from the slowness of the plate and the "flatness" of its sensitiveness curve between λ 5000 and λ 6800. As failures, however, the value of their inclusion is doubtful, while as representing relative sensitiveness they are deficient. The "blue-sensitiveness" of a plate divided by the "yellow- (or red-) sensitiveness" is the method

adopted by all photographic workers for expressing the chromatic value; and following this, measurement of these curves gives a value of about 1.2 or 1.3, while in reality the true value lies in the neighborhood of 11.0 or 12.0.

In all probability a part of the difference is due to the fact that the Lowell curves are estimated from prismatic spectra—a most unreliable source because the apparent sensitiveness is shifted toward the red

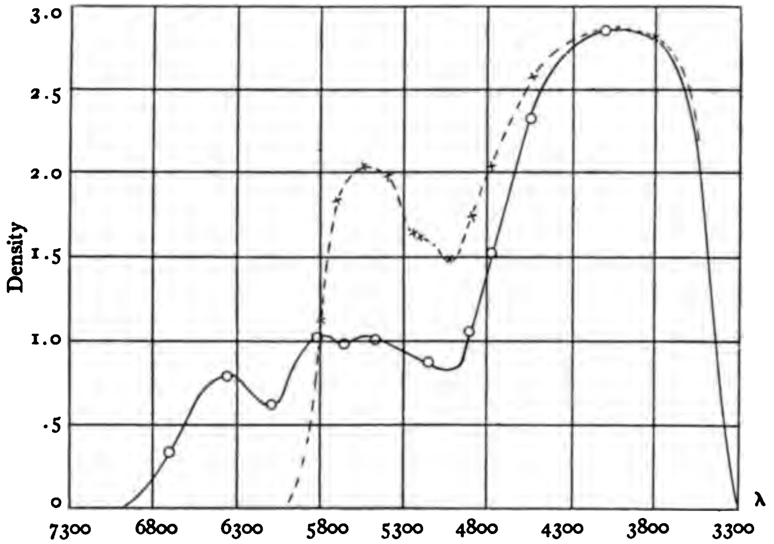


Fig. 9*b*

end by an amount dependent upon the refractive index and number of prisms used. Every investigator in photography knows that the maximum sensitiveness lies at λ 4100 not at λ 4600, and that in fast isochromatic plates of high quality the value of the yellow-green-sensitiveness is far below that of the blue-sensitiveness, and not in excess, as shown in the Lowell curves. What we are immediately concerned with, however, is the relative sensitiveness of the isochromatic plate after bathing.

If it were possible to sensitize an isochromatic plate for the red, and retain the relatively high maximum of sensitiveness in the yellow-green at λ 5100, then, in reality, we should still occupy the same position in regard to celestial photography as before; because although

it would be possible to gain greater speed it would be at the expense of definition; for it stands without possible argument, and as has been shown, that the greater the extent of objective curve embraced, the less critically sharp the image; although by consequent reduction in exposure time there would be less liability to unsharpness by waves of bad seeing. It is unfortunately true, however, that it is impossible to retain the value of the original isochromatic maximum.

Supplementary to a somewhat exhaustive investigation upon the action of the isocyanin dyestuffs upon the photographic plate recently concluded by the author,[1] about a dozen isochromatic plates were bathed in a combined bath of pinacyanol and pinachrome, under different types of bath, which included water, and dilute alcohol, plus ammonia, with subsequent washing in water, alcohol, dilute alcohol, and without washing. The strongest sensitizing action with this plate was found to result from an aqueous ammoniacal bath followed by a slight water washing, and rapid drying. The plate was then developed in the constant temperature tank, fixed, dried, measured, and plotted. This is the curve shown by the continuous line in Fig. 9*c*.

It has been suggested that, inasmuch as the objective in itself certainly possesses selective absorption, prismatic spectra were therefore very suitable, and in fact "quite the correct thing" for tests of relative sensitiveness. A series of spectra illustrating the absorption of the 40-inch objective (Fig. 10, Plate IX) shows, however, that beyond an absorption of about 200 Å. in the extreme ultra-violet there is no shift in the point of maximum sensitiveness, which remains constant at λ 4100. In previous papers the writer has demonstrated with some degree of completeness the incomparability of prismatic and diffraction spectra.

Inasmuch as we are mainly concerned at present with the action of the plate under a color-filter, a series of exposures was also made through a λ 5000 filter (precisely similar to that made for Professor Lowell) to the spectrum of diffused daylight, and the normal exposure measured and plotted. Similar exposures were also made upon the pinacyanol and pinachrome bathed "iso" plate, which was also measured (for equal-exposure times). These exposures, together with their resultant measured curves, are now shown in Fig. 11.

[1] *Astrophysical Journal*, 26, 299, 1907.

Measurement of the relative areas of these curves gives a result which is practically equal.

Exact tests are desirable, however, to determine the remaining constants of the plate, and to that end two isochromatic plates (bathed and normal) were exposed simultaneously in the revolving sector-disk machine behind the λ 5000 filter to diffused daylight. Both

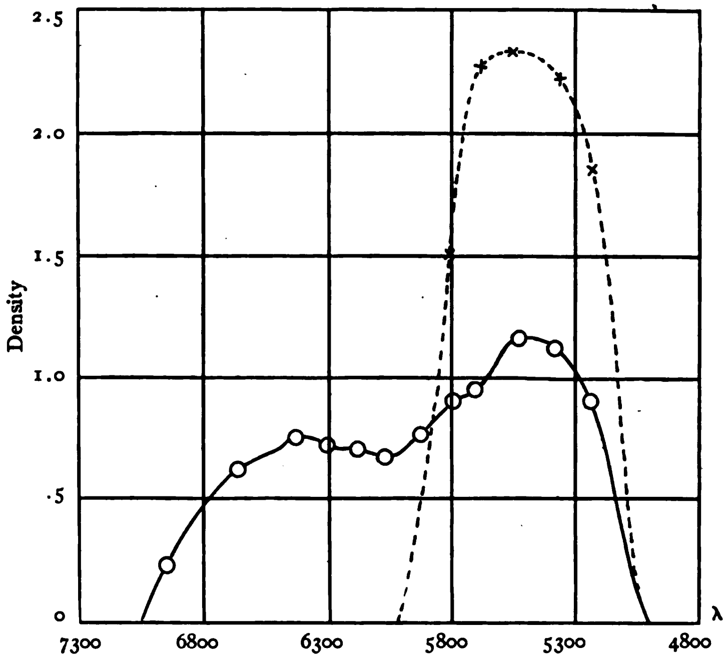
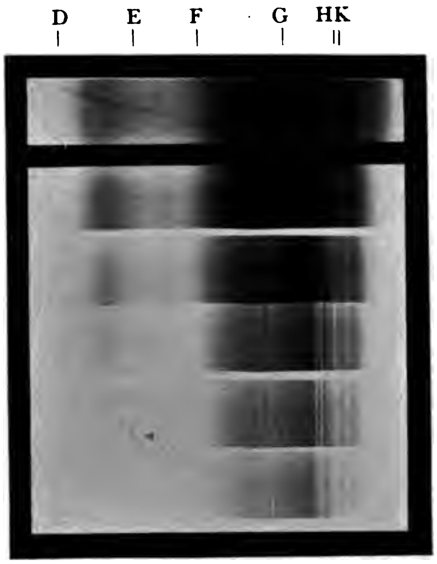


FIG. 11

plates were developed together at the one time, for the same length of time, and at constant temperature. They were then measured, and their curves are shown in Fig. 12.

Parallelism of the curves instantly indicates no change in gradation by bathing, while the extraction of the relative speed gives a value of 1.1 times, or 10 per cent. in favor of the bathed plate. As this is a negligible amount in plate density, it therefore confirms, by direct measures to selective light, the speed estimate obtained from the spectrum curves. Flat reproductions are also shown of the plates measured. It results therefore that there is no direct gain in speed

PLATE IX



a

FIG. 10

b

a. Cramer instantaneous isochromatic, unscreened.

b, Varying exposures through 40-inch objective to same sky as in *a*, and showing absorption in ultra-violet.

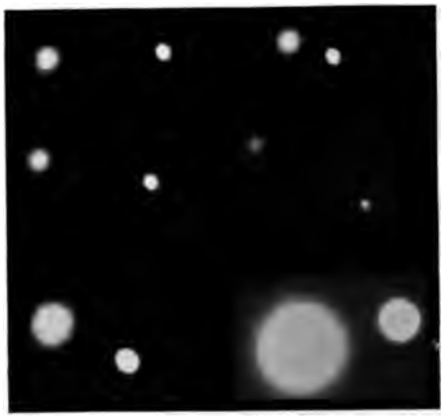


FIG. 7

Difference in quality of star images with color-filters absorbing at λ 4600 and λ 4900 respectively.

a

FIG. 13

b

Star images with 40-inch telescope photographed under identical conditions of "seeing", focus, exposure time, and color-filter (λ 4950) but upon (*a*) isochromatic and (*b*) red-sensitive plate.

but merely extension of spectral sensitiveness, the effect of which will be presently shown.

Taking up the "tests" by Lowell, I quote from *Lowell Observatory Bulletin*, No. 31, as follows: "Exposing a plate of this kind on *Mars*, in our usual way, ... I took half the number behind the old screen and then replacing it by the new one, took as many more, both sets

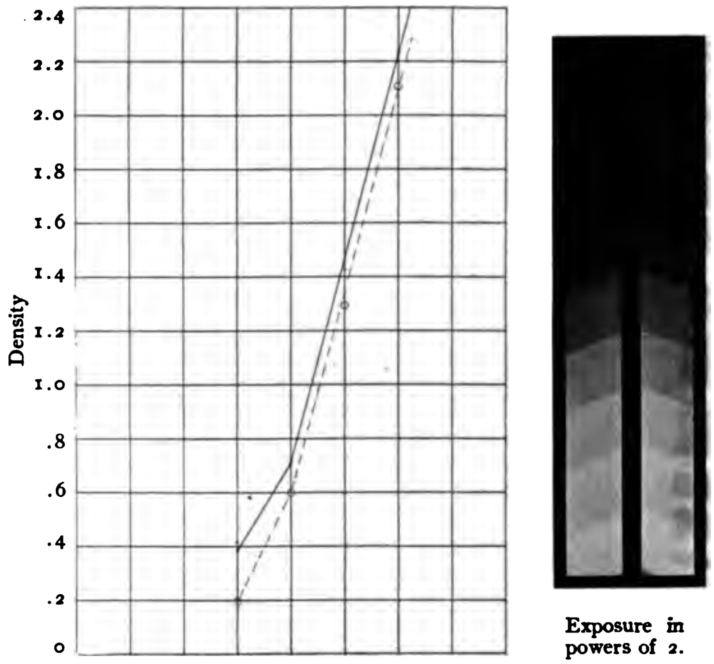


Fig. 12

being exposed equally. . . . . The results stood self-confessed, the detail came out sharper in the images taken with the orange screen than with those taken with the yellow. . . . ."

It would have been rather astonishing had the result ***not* shown** a difference; for when we consider that we are dealing with two entirely different color-filters, one of which transmits to λ 4800 and both of which are constructed for use with a plate possessing *one* single high maximum in the yellow-green, it would hardly be expected that they should give as sharp results when used with a plate possessed of *two*

active maxima. A more complete knowledge of the underlying principles would have predicated the result obtained. Had the λ 4800 filter been intended to be used on such a type of plate, then it would have been made to absorb the red end also.

That an extended sensitiveness does not compensate for a single maximum, is very well shown in the accompanying illustration (Fig. 13, Plate IX), which represents a series of (*a*) three exposures with the 40-inch telescope upon an instantaneous "iso" plate through a color-filter, at the critical focus; and (*b*) three more exposures upon the same star, through the same filter, for similar lengths of time, at precisely the same focus, with estimated identity of seeing, *but with a red-sensitive plate*. The increase in the size of the images, and the loss in sharpness, is readily apparent and needs no further comment.

If instead of a star we assume the case of the planet *Mars*, then we should have still a more decided example, because, according to Slipher, "the continuous spectrum of *Mars* is decidedly stronger in the orange red than that of the moon, while at E the reverse is true,"[1] whence an increased action in the out-of-focus red.

In making use of the color-filter λ 4800 with a red-sensitive plate, use is being made of more than double the amount of out-of-focus light than would be effective if the filter were used with the plate for which it was solely constructed; for, by the lowering of sensitiveness in the original isochromatic maximum, there is an increase in the burden of action which is thrown, first, upon the amount of blue light transmitted by the filter, and second, upon the region of enhanced sensitiveness at the red end, which is, equally with the blue, upon a rising branch of the objective's color curve.

With the orange filter the blue is cut off entirely, confining the action to the yellow-green and red, i. e., to the flat portion and a *single* rising branch, therefore a step nearer monochromatic conditions. Were the action taken entirely out of the red and *added to* the yellow-green, it would be a step still nearer true monochromatism, but such a change would result simply in practically duplicating the original compensated curve of the instantaneous isochromatic plate (see Fig. 11). It therefore follows, and is beyond the possibility of

[1] *Lowell Observatory Bulletin*, No. 17.

doubt, that if this filter be used in conjunction with the instantaneous "iso," still sharper images will be obtained than with the red-sensitive plate, because the active rays will be more nearly monochromatic.

The value of exposure combined with steadiness of air as influencing sharpness, (1) by reason of monochromatism of light acting, and (2) by only making use of a minimum disturbance, is shown by the excellence of direct solar negatives made with the blue light on ordinary non-orthochromatic plates, at a point where the color curve is rapidly approaching the vertical.

Important as is the correct appreciation of the isochromatic plate, color-filter, and exposure, yet of an importance equally commensurate is the rôle played by an efficient backing. It is safe to state, that in the delineation of astronomical detail the omission of backing causes at least a 50 per cent. loss of presentable results; while in each instance where such results have been attained, they would have been 100 per cent. better had backing been used. It is equally safe to say that the lack of knowledge on this point is even greater than on the chromatic adjustment of plate and filter, and yet the principle involved is of obvious comprehension.

Everyone who has photographed (and many who have not) has observed that where, for example, an exposure has been made upon a subject presenting fine dark markings upon a brightly illuminated area, in many instances this detail is either entirely obliterated or so grievously weakened as to be decipherable only with difficulty. In ordinary outdoor views branches or other objects cutting the bright sky are equally lost. This is the most common effect of *halation.* It is well known that when a ray of light after passing through the sensitive film and glass plate at any angle other than normal meets the air at the surface common to both, a portion of the ray is reflected again into the glass and impinges against the lower surface of the sensitive film. This amount of light reflected gradually increases with the angle of incidence until it reaches the critical angle at which point there is total reflection. The point upon the sensitive film where the ray falls may be considered as a point of emission and as the rays radiate in all directions around this point they thus form a circle in the plane of the sensitive film. This halation circle is very evident in photo-

graphic stellar negatives which have been made on *un*backed plates.[1]

In astronomical photography of an illuminated area such as the moon or the planets we have a precisely similar effect, for if on this illuminated area there be visually noted a thin or faint line, then the difficulty of recording it upon the sensitive film (even assuming absolute steadiness) is enormously increased if the plates used be not backed. Let *A* (Fig. 14) represent diagrammatically a section of the sensitive film and *B* the glass support, then the film at the narrow line *D* is (theoretically) unacted upon, while the illuminated area at *dd′* is, and is blackened by the subsequent action of the developer. If the plate be unbacked the rays illuminating the area *dd′* are refracted as in *d″* through *A* and *B*, and reflected back to the lower sensitive surface *P*, where they react upon the film, and upon development produce a blackening which in itself is sufficient not only to obscure but often entirely to obliterate the impress of the narrow line-image *D*.

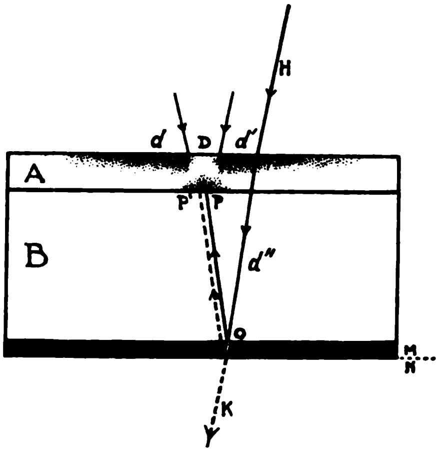


FIG. 14

It will of course be evident that if there be no variation in refractive index in the course of the path of the beam *HK*, there can be no reflection at *O*, hence no deposit at *P*. It follows, then, that if the plate be backed with a medium of similar refractive index to the glass, the beam will pursue its path without suffering reflection, provided that this medium be of such a color that it absorbs the active light-rays when they have entered.

If the layer of backing applied to the glass be represented at *M*,

[1] There is another form of halation caused by the spreading of the light laterally through the film, but inasmuch as this is a matter over which the photographer has no control, and is of very small effect, it is not necessary to consider it here.

then it results that the path of the incident beam H continues uninterruptedly until it reaches the air surface at MN, from whence it would be reflected to O'. However, if the layer M be colored red, then the light-rays will, by absorption, be robbed of their actinic value, so that only red light will be returned to P, which are of course inactive upon the film.

In practical work a backing composed of caramel mixed with a quantity of burnt sienna, or lampblack, has been found highly efficient. The compound is smeared heavily over the back of the plate with a stiff bristle brush.

When use is made of red-sensitive plates it would obviously be of no avail to color the caramel red because the modicum of light returned would be that to which the plate was sensitive, hence the best result for general work will be attained by the use of black. A damp wad of absorbent cotton readily removes the backing before development. [1]

To be most thoroughly effective, the backing should be in contact with the sensitive film and between it and the glass support. Such plates with a stained substratum are manufactured by several firms, but deficiency in the relative sensitiveness of the film has—so far—eliminated them from use in astronomical work.

In concluding these remarks upon the influence of filters and isochromatic plates in astronomical photography, no claim is made for general originality; in the specific application to astronomy the *treatment* is new, but otherwise all points are matters of common knowledge to the photophysical student.

We may summarize the foregoing in the following few sentences:

1. It is axiomatic that the closer the approach to monochromatic illumination, the more critically sharp will be the image. In practice the approach to monochromatic conditions is governed by the sensitiveness of the plate to the region under consideration.

2. With the use of the commercial isochromatic plate with its single secondary maximum in the yellow-green, there is no certain improvement in photographic definition (astronomically considered) by making use of a color-filter of greater mean absorption than λ 4900–λ 5000.

[1] If the plate be laid aside for some time before development the backing should be removed as its presence results in peculiar markings upon the film.

3. The two governing factors in successful astronomical photography of faint detail on illuminated areas (such as lunar or planetary work) are first, critical minimum exposure; and second, effecevti backing.

4. Given the necessary apparatus and material and assuming the ordinary ability to handle it, the personality of the operator exercises no influence upon the results obtained. These are, instead, relatively good or bad, as the "seeing" is excellent or poor.

YERKES OBSERVATORY
December 23, 1907

PLATE X

K H 4226.9

FIG. 1

FIG. 2

FIG. 3

b

a

K H 4226.9

REVERSALS OF CALCIUM LINES

DETERMINATION OF THE ORBITS OF SPECTROSCOPIC BINARIES

By W. F. King

On the assumption that the orbit of the star is an ellipse described about a center of force in one focus, the graph formed by taking the velocities in the line of sight as ordinates and the corresponding times as abscissas will be a periodic curve, from which can be determined the elements of the orbit, viz., the periodic time, the eccentricity, the longitude of the periastron from the ascending node, the projection of the major axis upon the line of sight, and the velocity of the system as a whole, that is, of the center of gravity of the system or of the focus of the elliptic orbit.

Various methods of determining these elements have been given, either geometrical, like that of Lehmann-Filhés, depending upon the comparison of areas of certain parts of the curve; or analytical, like that of Russell, using a Fourier series.

The curve of observed line-of-sight velocities differs from the true curve, by reason of errors of observation. The method of least squares may be employed to correct the first values of the elements, and to give the most probable values.

Spectra of certain types, however, are difficult to measure with accuracy, with the result that the graph of observed velocities may present differences from the theoretical curve which bear a considerable ratio to the velocity, so that the method is not to be depended upon unless successive approximations are made, entailing much labor. In such cases correction of the graph may be resorted to.

A free-hand curve is drawn, as nearly as possible of the form which the velocity curve should have, and as nearly as possible representing the observations. This curve may be adjusted so as to fulfil certain theoretical conditions, as to equality of areas, etc. (Lehmann-Filhés method). From this curve the elements are determined and from them an "ephemeris" is computed and a new graph representing these elements is drawn. Comparison of this with the former curve indicates correction to the elements, whereby a better accord-

ance with observations may be secured. A new ephemeris with corrected values of the elements is then made, followed by a comparison with the observations. By successive trials in this way, the values of the elements most nearly according with the observations are finally determined. This is the method which has been fol-

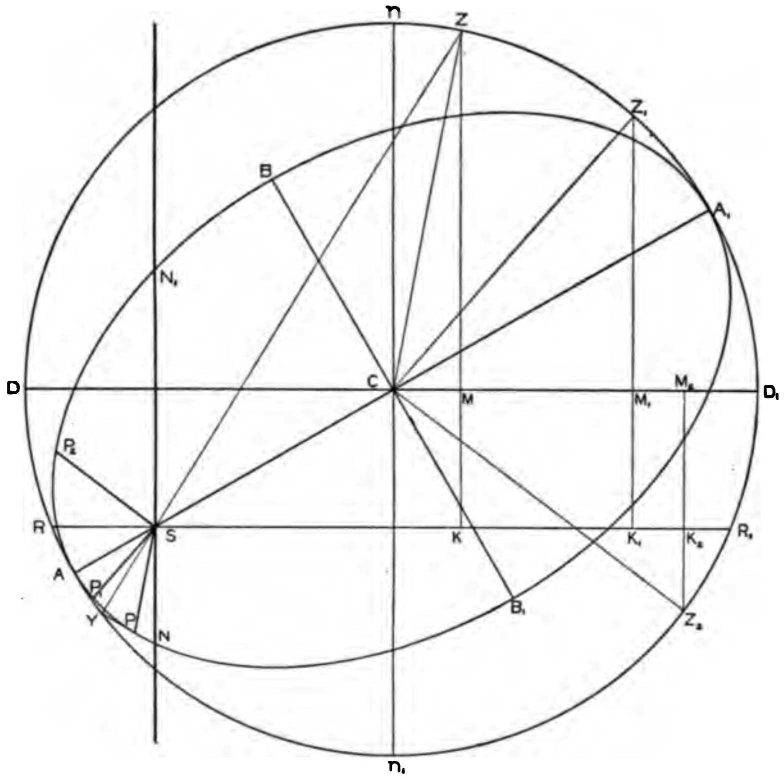


FIG. 1

lowed here in obtaining the elements of the orbits of early type stars, and I notice by some orbits recently published by the Lick Observatory, that the same procedure has been adopted there.

The object of the present paper is to present a method whereby as much as possible of the work of testing the accuracy of the successive graphs and of preparing the ephemerides may be done graphically.

Let the ellipse ABA_1B_1 in Fig. 1 represent the orbit of the star, S the center of force at the focus, AA_1 the major axis, N the ascending node, N_1 the descending node. Let P be the position of the star in its orbit at any time. We will suppose the motion of P to be clockwise. Draw SY perpendicular to the tangent at P. The point Y will, by a property of the ellipse, fall on the circle AZZ_1A_1, described on the major axis as diameter. If h is twice the area described in the unit time, v the velocity of the body in its orbit (with reference to S considered fixed). And if we produce YS to meet the circle again in Z,

$$SY \cdot SZ = SA_1 \cdot SA = a^2(1-e)^2 .$$

Hence

$$v = \frac{h}{a^2(1-e^2)} \cdot SZ .$$

SZ therefore is proportional to the velocity at P. It is perpendicular to its direction. Therefore the circle AZZ_1A_1 is the hodograph of the orbit, changed in scale in the ratio $1 : \frac{a^2(1-e^2)}{h}$ and turned through a right angle.

Draw RSR_1 through S, and DCD_1 through the center C, perpendicular to the line of nodes. Draw ZMK perpendicular to these two lines and cutting them in M and K. Then ZK is proportional to that component of the velocity relative to S, which is perpendicular to the line of nodes and in the plane of the orbit. If the plane of the orbit is inclined to the line of sight at an angle $90^\circ - i$, $ZK \sin i$ is proportional to the velocity in the line of sight.

Multiplying all the ordinates, as ZK, of the circle by $\sin i$, we evidently find for the hodograph of velocities in the line of sight an ellipse, of which the semi-major axis is proportional to CD or a, and the semi-minor axis to $a \sin i$.

It is to be observed that, by a property of the ellipse and the circle on its major axis CZ is parallel to SP. When therefore P proceeding from the ascending node has turned an angle u about the focus, the corresponding point of the elliptic hodograph has the eccentric angle u (counted from the minor axis). The velocity in the line of sight (still considering S at rest) is therefore

$$(ZM + MK) \sin i = a \sin i \cos u + MK \sin i .$$

This consists of a constant part $MK \sin i$ which is equal to $SM \sin i \cos \omega$ (ω denoting the longitude of the apse counted from the ascending node) or $ae \sin i \cos \omega$; and a variable part $a \sin i \cos u$.

Let us now conceive the scale of the figure to have been changed by multiplying all lines in it by $\frac{h}{a^2(1-e^2)}$; then the circle AZZ_1A_1

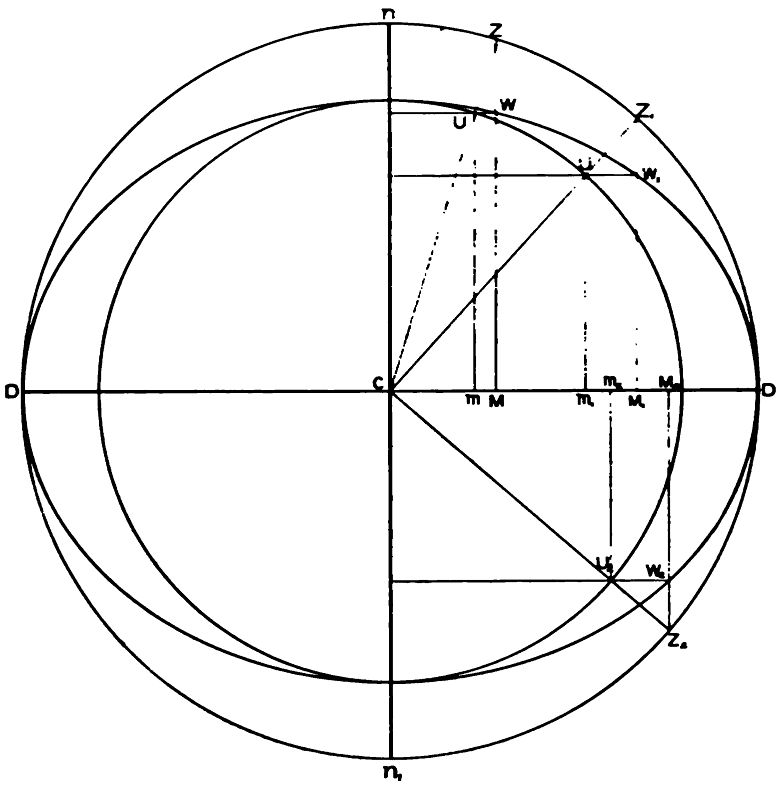


FIG. 2

becomes the hodograph in the orbit, and the ellipse produced by multiplying the ordinates perpendicular to RSR_1 by $\sin i$ becomes the hodograph of observed velocities. Comparing this ellipse with the graph of observed velocities in the line of sight, we see (assuming that the observations are without error) that the two curves have the same ordinates but different abscissas; those of the graph being proportional to the time, those of the ellipse being proportional to

the sine of the eccentric angle counted from the minor axis, that is, to the sine of the longitude (u) counted from the periastron.

Fig. 2 shows by the circle AZZ_1A_1 the orbital hodograph, and by the ellipse AWW_1A_1 the hodograph of the line of sight, having the ordinates MW, M_1W_1, etc., equal to $MZ \sin i$, $M_1Z_1 \sin i$, etc. Reduce all the abscissas of the ellipse in the same ratio, multiplying by $\sin i$. Then the ellipse becomes the circle UU_1U_2 described on the minor axis as diameter.

By consideration of the similar triangles ZMC, UMC, etc., it is seen that the new positions U, U_1 . . . . of the points W, W_1, W_2 fall on the straight lines joining C with Z, Z_1, Z_2, etc. Therefore the longitudes are unchanged, and the circle U, U_1, U_2, may be used as the equivalent of the hodograph of observed velocities. The problem is reduced to comparison of a circle with a curve in which the abscissas are proportional to the time.

The radius of this circle may be denoted by K. In terms of the elements of the ellipse

$$K = a\frac{h}{a^2(1-e^2)}\sin i = \frac{h \sin i}{a(1-e^2)} .$$

h is found from the periodic time U, for

$$h = \frac{2\pi a^2\sqrt{1-e^2}}{U} .$$

$$\therefore K = \frac{2\pi a}{U\sqrt{1-e^2}} \sin i.$$

K is equal to one-half the difference between the maximum and minimum velocities in the line of sight. When this and e have been found with the desired precision, the value of $a \sin i$ follows from the above formula. Figs. 3 and 4 will serve to illustrate the application in practice of the foregoing principles.

First of all, the observed velocities having been plotted as ordinates with the times as abscissas, a free-hand curve is drawn approximately of the peculiar form of the theoretical curve, and passing through or near to the points representing the individual observations. The curves in the figures may be taken as representing more or less closely such a graph of observations. In the figures the curves have been drawn with exactness for two eccentricities, 0.75 and 0.10.

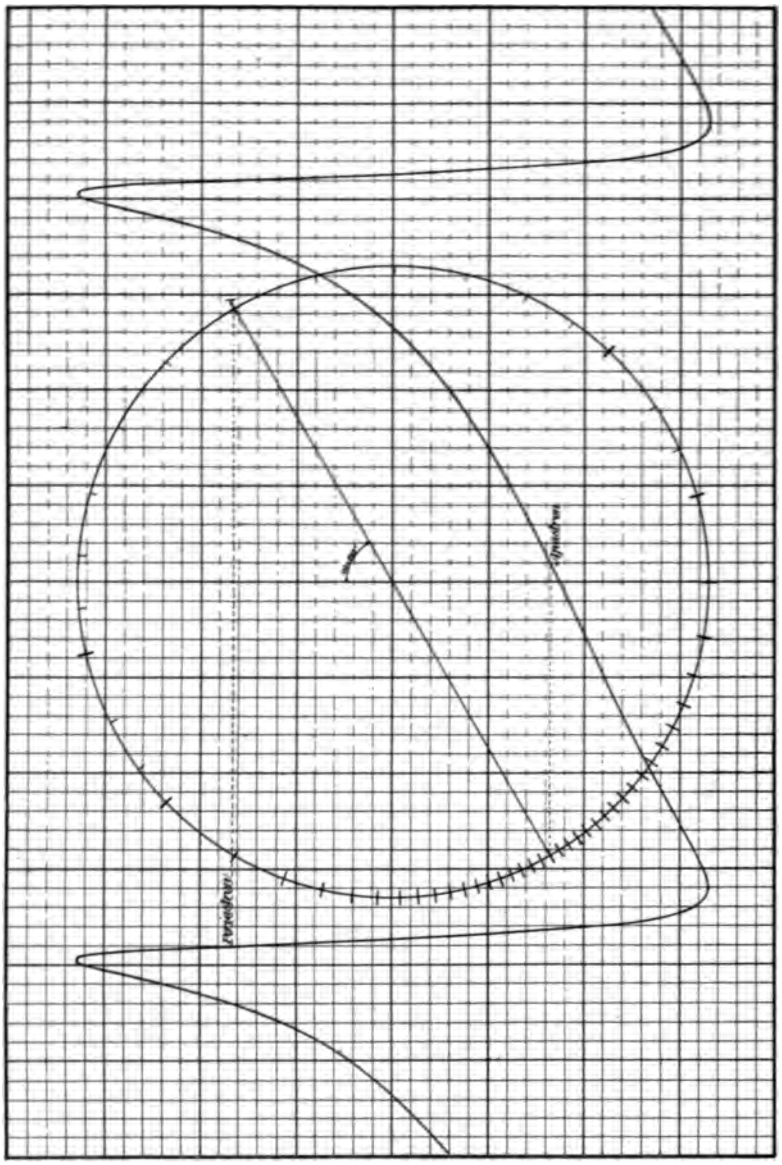


FIG. 3.—Graph for $e=0.75$, $\omega=60°$.

A circle is drawn having for diameter the difference between the maximum and minimum ordinates, and having its center on the line midway between the maximum and minimum points. This line, parallel to the axis of abscissas, may be called the central line of the curve.

The periodic time having been determined in the usual way, the abscissa-length corresponding to it is divided into any convenient number of equal parts, say 40; it should be an even number. The ordinates for these abscissas are placed in the circle, and the points so found in the circumference of the latter are marked. If the curve is of correct form, the points marked on the circumference will be found to lie at unequal distances from one another (except when the eccentricity of the orbit is zero), but these unequal distances will be found to vary uniformly. The points will be close together in the vicinity of one point of the circle, and will gradually separate as we proceed in either direction therefrom, until at the diametrically opposite point they reach their maximum distance apart. It is evident that the former point will correspond to apastron, and that of widest separation to periastron.

If it chances that one of the points of division of the line of abscissas corresponds to an apse, the divisions of the circumference will be equal at equal distances from the apsidal diameter. It not, they will not be equal on the two sides of this diameter, and the periastron will not coincide exactly with a division, but will lie within the greatest division of the circumference. Apastron similarly lies within the least division. We may, if we please, use the approximate positions of the apses thus found to set off our fortieths of the period along the line of abscissas from a new origin, whereby two of the points of the circle will more closely coincide with the apsidal points. In this manner, given a graph sufficiently near to the theoretical form, the position of the apsidal diameter may be determined and the angle which it makes with the axis of y measured with a protractor. This angle is the longitude (ω) of the apse.

It will be observed that this process furnishes a more thorough test of the accuracy of the graph than the method of equality of areas. If it is imperfect, the points on the circumference of the circle will not be distributed according to the regular order of increase

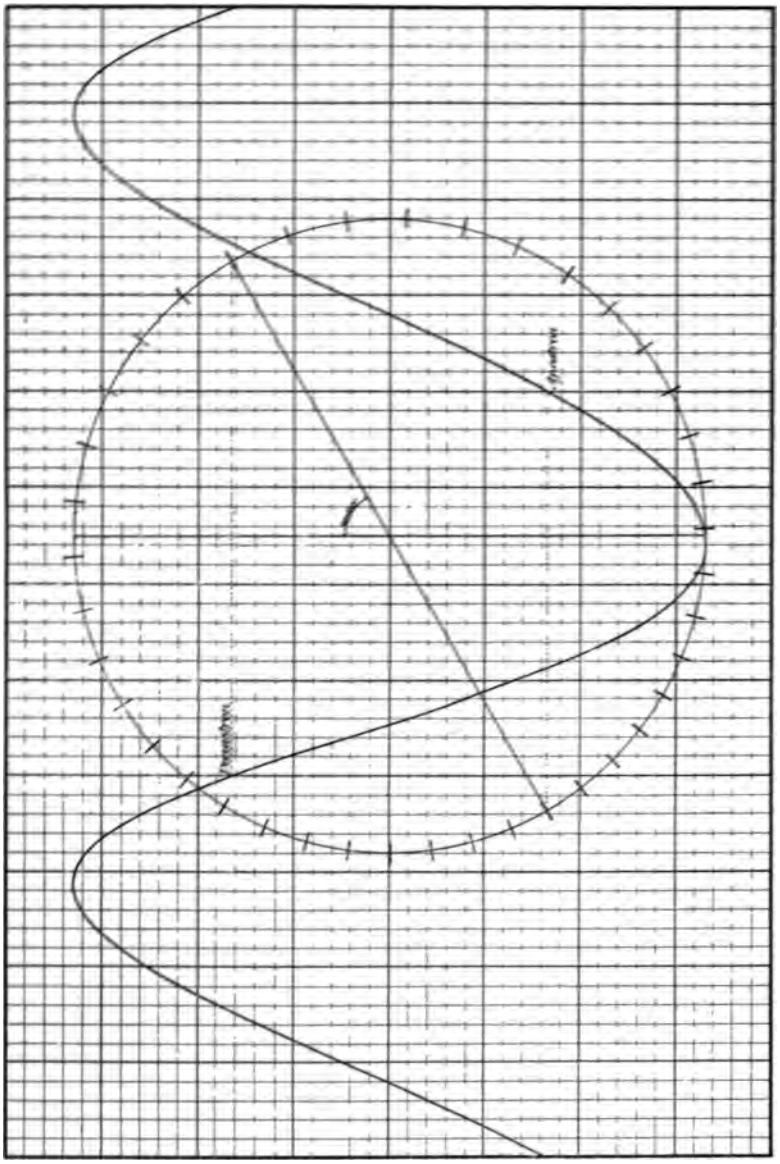


FIG. 4.—Graph for $e=0.10$, $\omega=60°$.

or decrease of the included arcs. If an ordinate of the graph is too long or too short, the corresponding point on the circumference will be too near or too far from the vertical diameter.

If the points of maximum and minimum velocity have not been well determined, the diameter of the circle will be too long or too short. In the former case all the points on the circumference will be crowded away from the vertical diameter; in the latter, toward it. Since the arcs of the circle represent differences of longitude corresponding to the given intervals of time, and $\frac{du}{dt}$ varies inversely as the square of the distance from the focus, we have by measuring the lengths d and d_1 of the arcs at points whose longitudes from the periastron are θ and θ_1,

$$\frac{d}{d_1}=\frac{(1+e\cos\theta)^2}{(1+e\cos\theta_1)^2},$$

whence the eccentricity may be found, when the position of periastron is known. If we measure the arcs at periastron and apastron, we have

$$\frac{d}{d_1}=\left(\frac{1+e}{1-e}\right)^2.$$

In applying this method, it is usually sufficient to measure the chords instead of the arcs, as only an approximation is needed at this stage. If the eccentricity is so large as to so greatly increase the arcs near periastron that they may not be considered equal to their chords, additional points may be interpolated near periastron.

It is not advisable, however, to spend too much time on these preliminary processes, as it is hardly possible that the first graph should be drawn with sufficient accuracy to give a good final result. The approximate value of the longitude of the apse and the eccentricity is, however, needed for the construction of a better graph, or "ephemeris."

The process in use here of approximate determination of the elements and constructing an ephemeris is as follows: Using the analytical formulae, the true anomalies corresponding to aliquot parts of the period of the binary are computed for any assumed eccentricity, and set off on the circumference of a circle, to be used as a protractor. A division of the period into 40 equal parts is in

general convenient, though for high eccentricities a further subdivision must be made for the neighborhood of periastron. The need for this is shown in Figs. 5, 6, and 7, which show protractors drawn for eccentricities 0.70, 0.75, and 0.80 respectively. The anomaly corresponding to one-fortieth of the period (or 9° of mean anomaly) is seen in Fig. 7 to be almost 90°. Intermediate lines near periastron have therefore been interpolated (shown dotted in the figures), dividing the one-fortieth next to periastron into 6 equal parts, each corresponding to 1°.5 of mean anomaly (this is found convenient with the tables we use, which give the solution of Kepler's equation for every half-degree). The second interval from periastron has been divided into 3 equal parts (3° of mean anomaly).

In Figs. 8, 9, and 10, drawn for small eccentricities, 0.05, 0.10, and 0.15 respectively, the parts of the circumference are nearly equal throughout. A number of these protractors, on transparent celluloid, have been made here. After the ordinates of the curve have been transferred to the circle, and the circumference marked off, a choice among the protractors will show which one agrees most closely with the marked points, and thereby the values of the longitude of the apse and the eccentricity of the orbit are obtained. Tests here have shown that the eccentricity can thus be determined within 0.01 when the velocity-curve is accurately drawn. If not accurately drawn, no such close approximation is necessary.

To construct an ephemeris, given eccentricity e, apse longitude ω, range of velocity $2K$, and period U, proceed as follows:

Draw a circle of radius K. Draw its "vertical" and "horizontal" diameters, producing the latter to the length necessary for the period U, according to the time-scale adopted. Set the protractor, made for eccentricity e, with its center over that of the circle, and its apsidal diameter making an angle ω with the vertical diameter. Plot the radial lines representing the anomalies corresponding to the divisions of the period upon the paper, noting their intersections with the circumference.

Having divided the line representing the period into a number of parts corresponding to the protractor, erect perpendiculars at these points of lengths equal to the corresponding ordinates of the circle. A free-hand curve drawn through the extremities of the ordinates gives

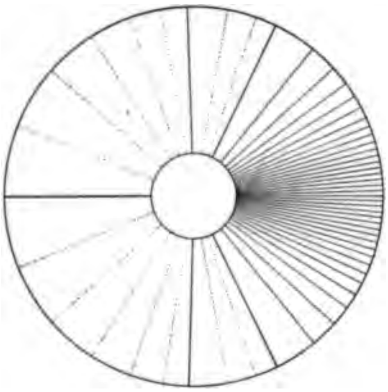


FIG. 7. $e=0.80$.

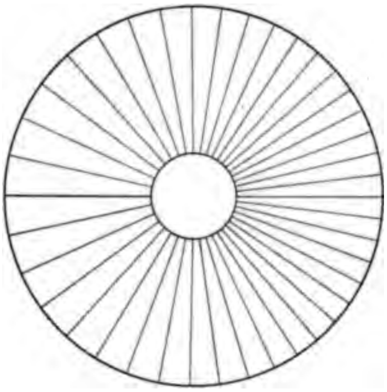


FIG. 10. $e=0.15$.

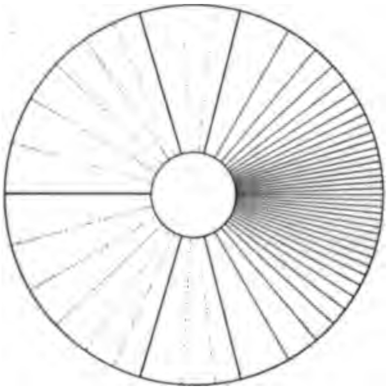


FIG. 6. $e=0.75$.

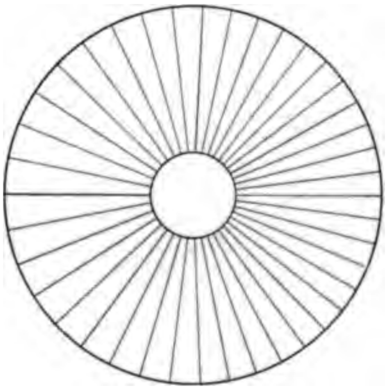


FIG. 9. $e=0.10$.

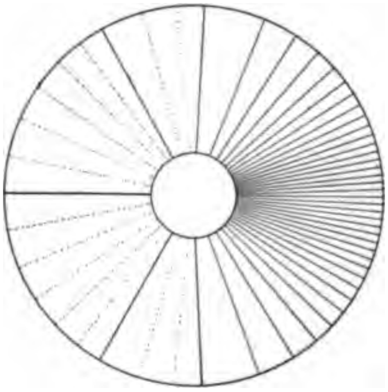


FIG. 5. $e=0.70$.

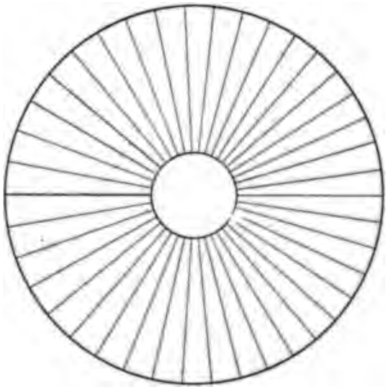


FIG. 8. $e=0.05$.

the required curve or "ephemeris." If, as will usually happen, the observations are plotted and the graph drawn on cross-section paper, the procedure will be considerably shorter. Draw the circle of radius K on the same or a similar sheet, place centrally on it the transparent protractor with the periastron point at the proper longitude ω from the vertical diameter, and note the ordinates of the points of intersection of the circumference of the circle with the radial lines of the protractor. These ordinates can be at once placed on their corresponding abscissas without either drawing or measuring.

If a set of protractors, such as in use here for values of e differing by 0.05, is not available, an alternative procedure is to use an ordinary protractor to set off arcs of 10°, say, and then the abscissas of the time velocity curve may be made equal to the mean anomalies corresponding to true anomalies of every 10° around the orbit. This can easily be done with a set of tables, such as have been computed here, giving the parts of the period corresponding to true anomalies of every 10° for all values of e from 0 to 1, at intervals of 0.05.

When the ephemeris has been drawn, it may be redrawn to a different apsidal longitude in the manner following. In Fig. 11, draw CA and CB equal to the radius K of the generating circle, and including an angle (β) equal to that by which it is desired to change the apse-longitude. It is evident that if the point C be placed on the central line of the curve, and A on any point of the curve, the point D where the ordinate of A meets a line through B parallel to the axis of abscissas will be a point on the curve corresponding to an orbit, of the same eccentricity e, and apse-longitude $\omega+\beta$. For if the ordinate of A is $K \sin(\theta+\omega)$, θ being the true anomaly, that of D will be $K \sin(\theta+\omega+\beta)$, and the abscissa (the time) remains the same.

To decrease the apse-longitude, set B on the curve and find the point D_1 on the ordinate of B, such that AD_1 is parallel to the axis of abscissas.

In practice a curve may be converted very rapidly. Let the construction be made on cardboard. After drawing the lines CA and CB, describe a circle on AB as diameter. Cut this circle out of the cardboard, marking on its circumference the point A. Cut the cardboard so that there is a tolerably sharp point at C. If the curve

has been drawn on cross-section paper, the intersection of the ordinate of A can be followed down by eye to its intersection with the circumference at D, and this point marked with a pencil. By operating thus with a number of points the curve can very rapidly be drawn to the changed apse-longitude.

If it is desired to change the scale of the velocities (i.e., the value of K) and the apse-longitude at the same time, this may be done by a slight modification of the construction above. Draw CA (Fig. 12) as before equal to K and $CB=K_1$ at an angle β with CA (to

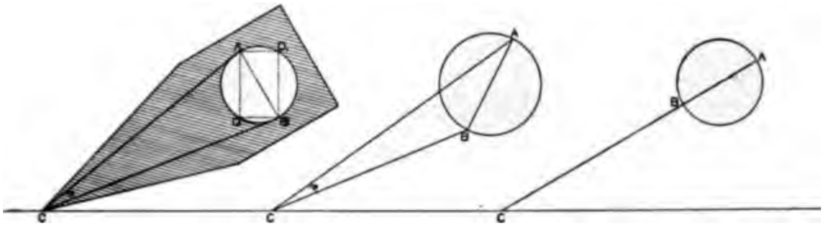


FIG. 11 FIG. 12 FIG. 13

right or left according as increase or decrease of apse-longitude is required). Draw the circle on AB as diameter, and proceed as before to draw the amended curve.

If it is desired to change K to K_1 without changing ω, CA and CB are drawn in the same line (Fig. 13) and the circle is described on the diameter AB as before.

These constructions suggest another method of drawing an ephemeris.

Let a number of standard curves be drawn for different eccentricities, and for any convenient apse-longitude, which may be 0 or 90°, or have any other value. Such a curve will differ from the graph of the observations both in the scale of the abscissas and also in that of the ordinates, and in general in different ratios.

Both abscissas and ordinates may be reduced with the pantagraph to the scale of abscissas set by the length of the period of the binary, and then the further change of scale of ordinates to agree with that of the observed velocities may be made in the manner outlined above, and at the same time any required apse-longitude

may be introduced. This method would have the advantage that the standard curve for a given eccentricity would need to be drawn but once, and therefore might be constructed very carefully. No convenient method of varying the eccentricity has yet been devised.

I wish to express my obligations to Mr. J. S. Plaskett for valuable assistance in preparing this paper for publication.

Dominion Astronomical Observatory
January 31, 1908

THE STAR IMAGE IN SPECTROGRAPHIC WORK. II

By J. S. PLASKETT

In the paper under this title published in this JOURNAL for April 1907, I described a series of tests made to determine the character of the image given by the system of visual objective with auxiliary photographic corrector, which is so generally used as the condensing system in spectrographic work. These tests definitely proved that the resulting image had negative aberration, that the focus for the edge rays was about 2.5 mm longer than the focus for central rays. It was also shown that the chromatic difference of spherical aberration of the objective at H_γ accounted for about 2 mm of this aberration, and that the correcting lens instead of removing the difficulty had added to it. Furthermore, a comparison of the relative exposure times at Ottawa with those of other equipments showed that the same difficulty probably existed elsewhere.

The matter, therefore, was deemed of sufficient consequence to justify an energetic attempt to improve the quality of the image and a new corrector was ordered from the J. A. Brashear Co. As the difficulty with the original corrector had been partly ascribed to its small size, 2.25 inches (57 mm) aperture, Professor Hastings enlarged the new lens to 4 inches clear aperture, with an effective aperture of 3.8 inches (96.5 mm). As it was impracticable to send the objective to Allegheny for use in testing the corrector, Professor Hastings devised an ingenious method of obtaining the correct figure. The radii of the surfaces and the thicknesses of the two elements were so computed that, assuming truly spherical surfaces, the system of objective and corrector would be free from aberration at the desired region. As spherical surfaces can be readily tested, the concave at the center of curvature and the convex, which in this case are of the same radius as one of the concave, by interference fringes, it was hoped that the new lens would give satisfactory images.

When it was received early in August last, it was found necessary, owing to its considerable distance, 15×3.8, or 57 inches (145 cm), within the focus, to add a support to the upper end of the mounting

in the form of a guiding ring into which the tube containing the corrector slipped. This ring was held in position and adjusted exactly in the optical axis by three radial bolts with nuts on the outside of the telescope tube. Accurate collimation after removal and replacement and also in every position of the telescope was therefore insured.

An examination of the appearance of the illumination pattern on the collimator and camera lenses, as observed by looking into the camera, sufficed to show that aberration was still present. The pattern was by no means uniform, although exhibiting some improvement over that given by the old lens.

As soon as possible the actual form of the image was determined, exactly as described in the former paper, by Hartmann's method of extra-focal measurements. The mean of a number of such measurements is given in Table I while the zonal differences of focus are platted in curve *B*, Fig. 1. For comparison the curve for the original corrector is reproduced in *A*, while *D* gives the differences of focus for the objective used visually.

TABLE I

ZONAL FOCI OF OBJECTIVE AND NEW CORRECTOR

Radius of Zone mm.	ϕ	New Correcting Lens			New Correcting Lens Refigured		
		Focus	Mean	Astigmatism	Focus	Mean	Astigmatism
28.......	45°	91.07		+0.26	91.87		+0.25
	135	90.55	90.81	−0.26	91.36	91.62	−0.26
47.......	0	91.55		+0.13	91.65		−0.21
	90	91.30	91.42	−0.13	92.07	91.86	+0.21
66......	45	91.04		+0.22	91.28		+0.20
	135	90.60	90.82	−0.22	90.89	91.08	−0.19
85.......	0	90.66		+0.07	90.27		−0.10
	90	90.53	90.59	−0.07	90.47	90.37	+0.10
104......	45	91.01		+0.30	90.46		+0.14
	135	90.41	90.71	−0.30	90.18	90.32	−0.14
123......	0	91.14		+0.12	90.33		+0.04
	90	90.90	91.02	−0.12	90.25	90.29	−0.04
142......	22.5	91.28		+0.03	90.38		+0.12
	67.5	91.41		+0.16	90.24		−0.02
	112.5	90.94		−0.31	90.04		−0.22
	157.5	91.36	91.25	+0.11	90.37	90.26	+0.11
160......	45	91.85		+0.25	90.28		+0.08
	135	91.36	91.60	−0.24	90.11	90.20	−0.09
178......	0	92.43		+0.15	90.50		+0.37
	90	92.14	92.28	−0.14	89.76	90.13	−0.37

It is evident from a comparison of the curves for the two correcting lenses that the same trouble exists in the new lens as in the old, for, although there is some slight improvement, it does not yet compensate for the chromatic differences. Its curve, however, is more regular and is nearly similar to the visual curve and this, taken in conjunction

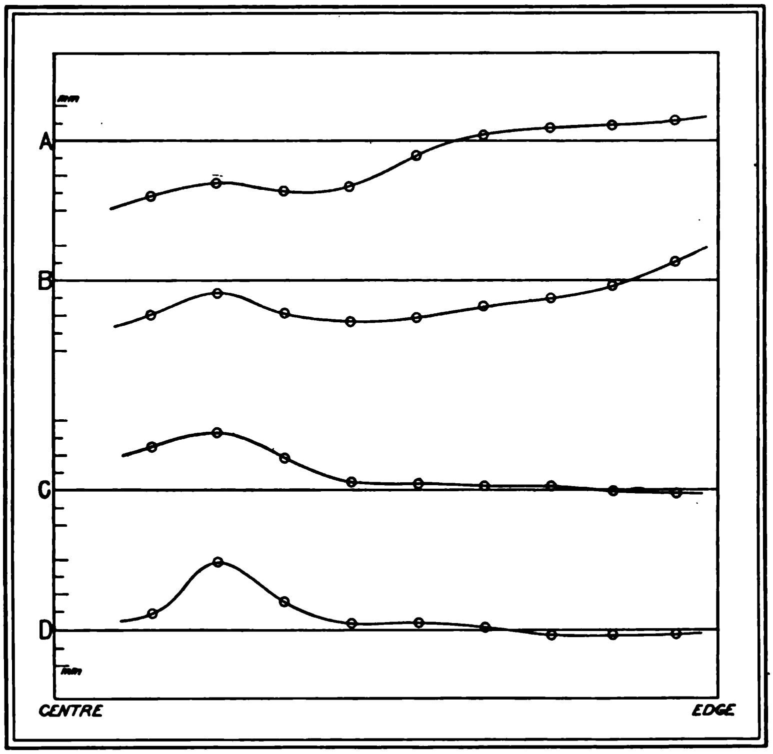


FIG. 1.—Zonal differences of focus.

with its larger aperture, should allow it to be more readily corrected by refiguring. In actual use, however, it is doubtful whether much improvement would be noticed on account of the greater inclination of the curve at the outer zones, which have the greatest effect in determining the character of the image. This disappointing failure to fulfil the computed results must doubtless be ascribed to the small unavoidable departures of the actual from the computed radii of curvature, thickness, etc., of the elements, which may easily

account for the small remaining aberration. The only chance of improvement appeared to be in refiguring the surfaces to introduce the required amount of positive aberration. A reference to Fig. 1, curve *B*, shows that, if the focus for the edge with respect to the center be shortened by 1.5 mm, and if this shortening be gradually decreased until a medium zone is reached, the image would be as good as desired.

Owing to the difficulties and delays involved in sending the 15-inch objective to Allegheny, the corrector alone was taken there, particularly as Mr. McDowell was certain that he could introduce the required amount of aberration. Preparations were made for confirmatory tests by the Hartmann method in addition to Mr. McDowell's visual tests. The method of testing adopted, which followed as closely as possible the actual conditions under which the lens was to be used, consisted in forming a beam of parallel light by placing an artificial star at the principal focus of a 6-inch objective. A 4-inch objective of 60 inches focus placed in this beam formed an image of the star, and, if the corrector were inserted three inches from this objective, it would intercept a pencil of the same diameter and convergency and at the same distance from the focus as when used in its computed position at Ottawa. Moreover, tests by the Hartmann method or the ordinary knife-edge tests were equally easily applied.

A preliminary Foucault or knife-edge test with red monochromatic light, which was used in this test on account of the difficulty of obtaining monochromatic blue, showed that the edge focus of the system of 4-inch objective and corrector was about 0.7 mm shorter than the focus at the center. This is an indication, since presumably the 4-inch objective is free from aberration for light of this wave-length, that positive aberration to the extent of about 0.7 mm was present in the corrector. The chromatic difference of the 15-inch objective is about 2 mm, and hence this test showed that the corrector required an increased amount, previously estimated at about 1.5 mm, of positive aberration. A Hartmann test, using photographic light, showed the difference between center and edge to be about 0.2 mm. The difference between this and the visual test of 0.7 mm is almost exactly that due to the chromatic difference of the 4-inch objective.

Thus all the tests were in accord with one another and gave increased confidence in the reliability of each.

After a few minutes' figuring of the outer concave surface a visual test showed a difference between center and edge of about 4 mm, which was considerably too great. However, Mr. McDowell's skill in figuring enabled him at the second trial to get the surface so nearly right that repeated tests by different observers showed the difference from the required amount, 2.2 mm, to be indeterminable. A confirmatory Hartmann test showed the positive aberration present to be about 1.8 mm, 1.6 mm greater than before figuring.

The corrector was therefore considered completed, and the short time required to polish it, less than five minutes if the time spent in carrying it too far and bringing it back be deducted, is an indication that its failure to fulfil its computed purpose is probably due, as was stated above, to slight deviations of the actual from the computed figures unavoidable in practice. In this connection I wish to express my admiration of the skill of the John A. Brashear Co. in producing perfect optical surfaces, and my appreciation of the generous manner in which they have treated us in this as well as in all other matters.

Immediately upon my return from Allegheny, a Hartmann test was made of the performance of the refigured corrector. Using lantern plates and *Capella* as in the previous paper, the mean of a number of measures is given in Table I and shown graphically in curve *C*, Fig. 1. A comparison of curves *C* and *D* shows that the deviations from the mean focus are less with objective and corrector than with objective alone, although this advantage is probably counterbalanced by the greater astigmatism of the former system in the outer zone. If Hartmann's criterion "*T*" is computed for objective and corrector, as was done in the previous paper for objective alone with a value of 0.141, it is found to be 0.118, showing the system to be almost perfect so far as zonal aberration is concerned. The small deviation near the center is of no practical importance, owing to its relatively small area and to the narrow convergency of the pencils, and probably arises, as the visual curve shows, in the objective itself.

Determinations of the color-curve of objective and corrector for a median zone were made by Hartmann's method and the results are platted in Fig. 2. Curve *A* is for the corrector in its computed position

57 inches (144.8 cm) above the focus, curve *B* 59 inches (149.9 cm), and curve *C* 54 inches (137.2 cm) above the focus, while curve *D* is for the old corrector. These curves show that the point of minimum focus can be shifted to the red by lowering, and to the violet by

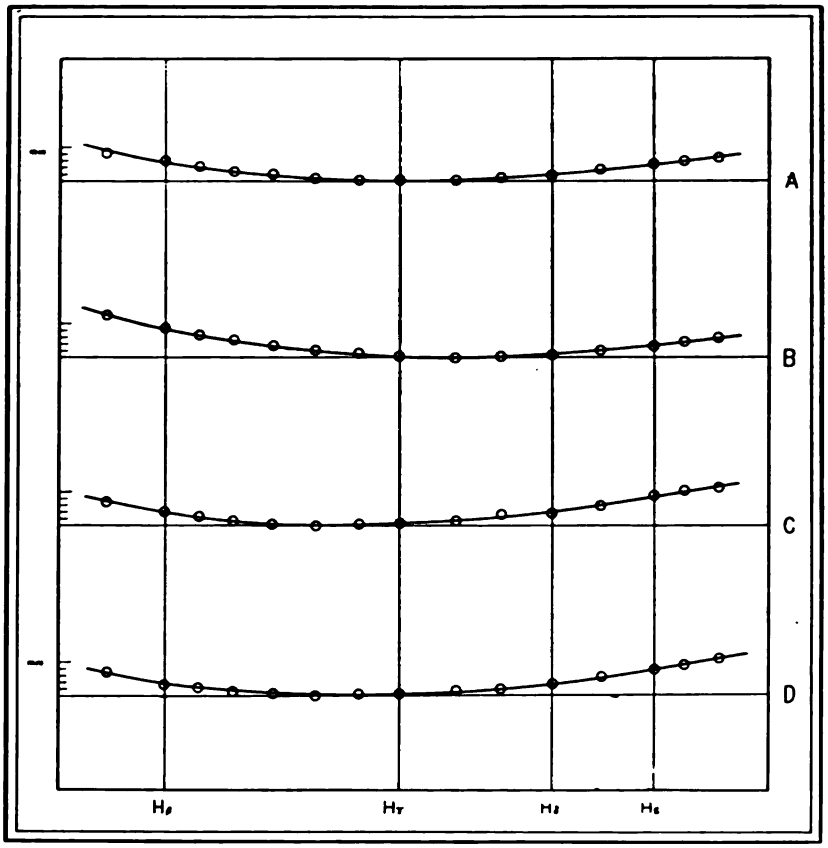


FIG. 2—Color curves of new corrector.

raising the correcting lens; this knowledge may be of value if, for any cause, the portion of spectrum under observation were changed. As is to be expected, the color-curves for new and old corrector do not differ appreciably in form.

It may be of interest to give some figures showing the exposures required to obtain measurable spectra with the new correcting lens.

In the three-prism plates, which have been confined to solar-type stars, the region measured lies between λ 4340 and λ 4580 and the exposure was sufficient to give good intensity over this range. In the single-prism plates the region measured lies between H_β and K, and the exposure was sufficient to allow K to be accurately measured and to sharpen up the diffuse *H* lines. I should estimate this exposure to be more than twice that required in a solar-type star of the same photographic magnitude around λ 4500. In single-prism work in order to render the spectrum more uniform in intensity the slit is placed about 2 mm below the minimum focus so that star light of wave-lengths about λ 4000 and λ 4800 is in focus on the slit. For this purpose the color-curves obtained above prove very useful.

TABLE II

THREE-PRISM SPECTROGRAPH

Linear dispersion 10.0 tenth-meters per mm at H_γ

Star	Phot. Mag. *Draper Cat.*	Slit-Width	Exposure
η Piscium...........	5.02	0.038 mm	70 mins.
ε Cygni.............	3.85	0.030	35 "

TABLE III

SINGLE-PRISM SPECTROGRAPH

Linear dispersion 30 tenth-meters per mm at H_γ

Star	Phot. Mag.	Slit-Width	Exposure
ι Orionis............	3.4	0.030 mm	10 mins.
o Andromedae........	3.9	0.030	25 "
ψ Orionis...........	4.6	0.035	40 "

As these figures show, the exposure times required, considering the size of the telescope, are short and compare favorably with those of any installation, although enough data have not yet been secured with the three-prism spectrograph to make accurate comparisons possible. If the magnitude of *η Piscium*, which is assigned as 5.02 in the *Draper Catalogue*, is reliable, then a star of the fifth photographic magnitude could be photographed in two hours with a slit 0.025 mm wide and a linear dispersion of 10 tenth-meters per millimeter, a very efficient performance for a 15-inch objective, especially

in the generally unfavorable conditions at Ottawa. Again, if the exposures given with the single-prism spectrograph be reduced by 50 per cent. or more, as would occur were the slit set at the focus for λ 4500 and the spectrum made measurable around this region, they would indicate similarly a very efficient condensing system. So far as the data at hand go, they indicate a decrease in the required exposure time with the new corrector of upward of 50 per cent. and if Table V[1] of the previous paper be reconstructed under these new conditions it would show the relative efficiency of the Ottawa installation to be equal if not superior to that of any other.

The successful issue of the attempt to improve the photographic image given by the Ottawa objective and corrector is of value, not only on account of the increase in the range and efficiency of the equipment, but also because of the greater freedom from chance of systematic displacement of the lines due to the more uniform illumination of the collimator insured by an image free from aberration. It is also of value as showing the possibility of obtaining a practically perfect corrector without sending the objective to the optician.

Another advantage, so far as this investigation is concerned, is the assurance of having a star image free from aberration as a starting-point for a trustworthy investigation into the actual effect of atmospheric disturbances on such an image. Some experiments were made, as recounted in the previous paper, on the effective diameter of the star image but, owing to the aberrations present in the old corrector, the results obtained gave only the combined effect of aberration and atmospheric tremor. Since the former has been removed, a repetition of the experiments should give an accurate knowledge of the effect of the latter. Newall has already given,[2] principally from theoretical considerations, a very valuable discussion of the effect of such an enlarged image on the design of spectrographs, and it seemed to me that a description of some experiments bearing on the same point

[1] Since the table referred to was published, Mr. V. M. Slipher has informed me that the exposure times assigned to the Lowell equipment were too large. They were taken from his paper on "Standard Velocity Stars," but Mr. Slipher states that the early plates were not only overexposed, but that the spectrum was made much wider than necessary. Under such conditions the Lowell equipment would make a much more favorable showing.

[2] *Monthly Notices*, 65, 608, 1905.

together with the conclusions reached would also be of value. Newall considers the effective star image to be composed of a central "core," as he calls it, surrounded by a more diffuse "tremor-disk" and calculates on such an assumption the quantity of light transmitted by slits of different widths for different diameters of core and tremor-disk. I shall attempt to show how the percentage of light transmitted may be determined experimentally and obtain from that and other experiments some conception of the form and dimensions of the star image.

If one examines the visual star image in a telescope by an eyepiece of moderate power, it cannot escape notice that the image is not stationary, that it is displaced in all directions from its mean position, and moreover that the central diffraction disk is frequently expanded in a greater or less degree. These two phenomena, due entirely to atmospheric effects to which should be added the light in the bright rings surrounding the central disk, may be assigned as the cause for the enlargement over theoretical dimensions of the star image on a negative. The effects are all summed up in the resultant image, very much increasing its diameter over that due to the central disk alone.

As a test of this hypothesis stars of different magnitudes were photographed, a number of different exposures being given to each star. The diameter of the images varied from 0.050 mm equivalent to $1''.8$ for a faint star with short exposure to 0.130 mm or $4''.7$ for a bright star with medium exposure. A number of these images of moderate exposure had a central nucleus of about $2''$ diameter surrounded by an outlying penumbral portion some $3''$ or $4''$ in diameter. The diameter and intensity of this penumbra increased with increase of exposure, until in the longer exposures on bright stars its intensity became equal to the nucleus, resulting in the largely increased diameter noticed. Photographs of *Capella* on lantern-slide plates with exposures from 10 to 40 sec. gave images of diameters from 0.13 to 0.17 mm, or from $4''.5$ to $6''$, and these images differed from those of shorter exposure on fainter stars by being more sharply defined at the margins and of uniform intensity throughout. The minimum effective diameter of star images seems therefore to be in the neighborhood of $2''$, though this will evidently vary with the conditions of seeing. The diameter remains nearly the same for a considerable range of exposure and then begins to increase until it reaches about $6''$, although

part of this may be due to the spreading of the light in the film or to halation.

If the star be allowed to trail on the plate, the width of trail will give us a measure of the effective diameter of the image, and its appearance some idea of its character. The trails in every case, even in good seeing, were broken and jagged, showing the dancing of the image previously referred to. The enlargement or blurring is shown by the widths of the trails, which for a third-magnitude star on a lantern-slide plate ranged, even in the narrowest short parts, from 0.035 to 0.048 mm, or from 1″.25 to 1″.7, upward of twice the diameter of the central disk. For *Capella* the widths were from 0.050 to 0.065 mm, 1″.8 to 2″.3. If the microscope wires were set tangent to a longer strip of the trail, the above figures were increased about 30 per cent. For the old corrector the widths ranged from 0.070 to 0.110 mm, practically twice as great as with the refigured lens.

The widths of star spectra made under different conditions of exposure and focus were also measured and ranged from 0.048 to 0.110 mm. In order to prevent any widening due to drift in right ascension, the spectrograph was turned in position until the slit was parallel to an hour circle. As the focal lengths of collimator and camera are equal, the widths obtained give a measure of the effective diameter of the star image. The star used was *Vega*, which was chosen for two reasons: the shortness of exposure required insuring freedom from possibility of drift, and the type of spectrum rendering it certain that the full width was obtained. Similar experiments with solar-type stars showed that the discontinuous nature of the spectrum rendered it apparently much narrower.

It will be of interest here to give a table showing the increase of width with increase of exposure.

TABLE IV

Exposure	Width	Angular Diameter
5 secs	0.048 mm	1″.7
10 secs	0.049	1.7
15 secs	0.060	2.2
20 secs	0.075	2.7
30 secs	0.086	3.1
45 secs	0.095	3.5
90 secs	0.110	4.0

The above figures show how the outlying parts of the "tremor-disk," which has a "core" of about 1."7 diameter, increase the width of the spectrum when the exposure is sufficiently prolonged to allow them to act on the plate.

With the old corrector the widths ranged from 0.085 to 0.115 mm, considerably wider than those given above.

The above experiments indicate that Newall's hypothesis in regard to the character and dimensions of the star image is in close argeement with the observed facts. The dimensions seem to point to a tremor-disk about 5″ diameter with a core 2″. If the proportions of the light transmitted by slits of different widths on which such an image is incident be computed, and if we obtain, exactly as was done in the previous paper, the proportional exposures required to obtain spectra of equal intensity over the same range of slit-width, a comparison of the two should show whether the assumption made is justified. In any case the experiments will show the actual loss at the slit, and this will be of value as indicating the direction in which improvement may be reached.

Three stars were used in this test *Vega*, *Capella*, and *γ Cygni*, and the spectra were made of the usual width, the greatest possible care being taken to insure uniform exposure over that width in order that they could be accurately compared. The exposures were so regulated as to obtain as nearly as possible equal intensity. Thus, neglecting plate factors which, within the limits of exposure time and intensity used, will not appreciably affect the result, a direct estimate of the percentage of light transmitted is obtained. The mean of a number of tests gives figures according to Table V; the seeing during these tests being slightly above the average.

In the following table the fourth column gives the observed times for equal intensities of spectrum while the fifth is the same with a correction for diffractional losses in the collimator with the narrower slit-widths. The sixth column is computed on the basis of Newall's hypothesis for a tremor-disk 5″ diameter with a core of 2″. The computed percentages are slightly higher than the observed, indicating that the actual image is probably somewhat larger than the dimensions chosen for the computed one. It must be remembered, however, that these figures are approximate only, the nature of the test not

TABLE V

SLIT-TRANSMISSION

Slit-Width			Comparative Times for Equal Intensity of Spectrum		
Div.	Linear	Angular	Observed	Eliminating Diffraction	Computed
1	0.025 mm	0″.91	100	100	100
2	.050	1.82	40	50	54
3	.075	2.73	27	35	39
4	.100	3.64	25	32	34
5	.125	4.55	23	29	31
6	.150	5.45	23	29	31
8	.200	7.27	23	29	31

permitting determinations closer than 5 per cent. Moreover, a change in the steadiness of the air would change the observed figures very considerably, the effect of poorer seeing being to increase the diameter of the tremor-disk and core and consequently diminish the slit-transmission.

All the experiments on the diameter of images, widths of trails and spectra, and loss of light at the slit, indicate a form of star image which is of about the same dimensions and character as that supposed by Newall, and we may with confidence consider that the actual effective image of a star on the slit-plate is very much larger than has generally been supposed. Moreover, as the zonal tests have shown that the condensing system is free from aberration and the image almost perfect, the enlargement must be due to atmospheric disturbance of the wave-fronts and cannot be overcome by any optical system. It is evident, however, from the similar tests in the previous paper where less than 20 per cent. of the incident star light was transmitted by a 0.025 mm slit, that an optical system free from aberration is necessary for the most efficient performance. Even with such a system, however, only 30 per cent., or less, of the light collected by a 15-inch objective, can be transmitted by a 0.025 mm slit. This difficulty is much more serious with objectives of longer focus, as the image is probably enlarged proportionally. Indeed, Wright's tests[1] show that the Mills spectrograph makes use of only about 12 per cent. of the light collected by the 36-inch telescope, and

[1] *Publications of Lick Observatory*, 9, Part 3.

this in the unequaled atmospheric conditions of Mt. Hamilton. Part of the advantage of increase of aperture is thus lost by the consequent increase in the effective diameter of the image. The only means of diminishing this loss lies in using wider slits in our spectrographs. For example, a slit 0.05 mm wide with the 15-inch objective would transmit about 55 per cent. of the incident light, while a slit 0.075 mm wide, nearly 80 per cent. Unfortunately, wider slits mean diminished purity and loss of accuracy, although, as some experiments here have shown, the probable error of radial velocity determinations in stars of early types by no means increases proportionately with the increase of slit-width. These results also indicate the importance of using as large a collimator aperture as is consistent with homogeneous prisms, the consequent longer focus allowing increased slit-width with equal purity. The question of spectrograph design is, however, beyond the scope of the present paper, although I hope to publish shortly some experimental results bearing on this question.

I wish to express in conclusion my indebtedness to the Director, Dr. W. F. King, for his hearty and helpful co-operation in this work.

DOMINION OBSERVATORY, OTTAWA
December 1907

ON THE SPECTRUM OF CALCIUM

By JAMES BARNES

The study of the conditions which produce changes in the intensity and distribution of light in spectrum lines has direct application to astrophysical problems. In some former work[1] on the spectrum of magnesium the author found that a reduction of the pressure of the gas surrounding the arc influenced the intensity of many of the lines, when other conditions, such as the strength of the current, were kept constant. The intensity of the remarkable line λ 4481 produced in the arc in air or hydrogen at low pressures is constant for changes of current-strength from 0.5 to 7.5 amperes. Hartmann[2] showed that this line, produced in the same way but surrounded by air at atmospheric pressure, rapidly increases its intensity when the current is diminished through the above range.

Since calcium is a very important element in solar and stellar phenomena, and as a quantity of it can now be obtained in the metallic state at a reasonable price, easily turned into electrodes, and the arc made and remade even in air with small currents with much less difficulty than with magnesium, a continuation of the former observations, using calcium metal in place of magnesium, was an object of this report. At the same time the interesting papers of Humphreys[3] and of Konen and Hagenbach[4] on double reversals suggested an attempt be made to obtain the conditions which shall produce in a terrestrial source the double reversals of the H and K lines. These lines, I believe, generally appear doubly reversed in the spectrum of the sun's disk, which is usually explained by the existence of a luminous layer of calcium vapor in the chromosphere at a higher temperature than the layers above and below it. Finally it was expected that the arc between electrodes of pure metallic calcium burning in almost a vacuum would probably be the best condition for the appearance of new lines.

[1] *Astrophysical Journal*, **21**, 74, 1905.

[2] *Sitzungsberichte der K. Preuss. Akad. der Wissenschaften*, **12**, 1, 1903

[3] *Astrophysical Journal*, **18**, 204, 1903.

[4] *Ibid.*, **19**, 111, 1904.

The work was carried out with the following apparatus: A Rowland concave grating of six feet radius was used. Photographs were taken only in the first-order spectrum because the grating was very bright in this order, and also for the reason as pointed out by Humphreys, that it is possible to obtain false double reversals by the superposition of a sharp line of one order upon the reversal of another line of another order. Using the first order it is impossible for any of the ultra-violet lines of the second order to give such results in the case of any of the calcium lines considered.

The electrodes of metallic calcium were made about one cm in diameter and were mounted in an ordinary hand regulator for the work at atmospheric pressure. The time of exposure varied from half an hour to a fraction of a minute, depending on the strength of the current. During the long exposures necessitated by the small currents, the small number of times the arc required to be remade was very gratifying. When the arc is made a large number of times, as is required in the case of magnesium, conditions which approach those existing in the spark must certainly be produced.

For the observations at low pressures the electrodes were mounted in a large brass vessel of about 16,000 cc capacity, built specially for this purpose. It contained a long side tube closed by a quartz plate through which the radiation passed to the slit. There was also an air-tight arrangement for adjusting from without the distance between the electrodes. This vessel was exhausted by a Geryk pump and the pressure could easily be kept constant at one cm of mercury during the longest exposure.

The current was obtained from the college 110-volt circuit, and its strength varied by resistances consisting of incandescent lamps and iron rheostats.

CURRENT-STRENGTH AND PRESSURE EFFECTS

A systematic series of photographs of the arc in air at atmospheric pressure was taken. They show no remarkable changes in the intensities of the lines when the current is varied from 0.5 to 20 amperes. The first line to reverse is λ 4226.9, which occurs when the current-strength is only about one ampere. The K line reverses next and then the H line. These take place when the current is about 3

amperes. With heavier currents most of the lines are of course broadened and reversed. The lines $\lambda\lambda$ 4685.4 and 4355.4 were never obtained reversed. The two spark lines $\lambda\lambda$ 3737.1 and 3706.2, which are very strong in the spark spectrum, appear in the arc spectrum and are somewhat stronger when the current is small. They are however not increased in intensity when the arc is in a vacuum.

The variations which do occur in the intensities of the lines in the arcs of 0.5 and 20 amperes are generally toward an increase with decrease of current. Hale and Adams[1] attribute this to the temperature variation, but it seems from the following observations that the density of the surrounding vapor must play a rôle. With the arc in a vacuum plates were taken for current-strengths from 0.5 to 12 amperes. The only line that ever appeared reversed was λ 4226.9 and this only at the larger currents. At 12 amperes the H and K lines are no broader or brighter than at one ampere. Plate X, Fig. 1, shows how clearly these lines are defined in the arc of 12 amperes in a vacuum. The simplest explanation which will account for these observations is that the line λ 4226.9 is characteristic of calcium vapor when it is dense, while the H and K lines are characteristic of the rarer vapor. If this is the case the intensity of λ 4226.9 would be very large in the immediate vicinity of the metallic poles, the cooler and rarer enveloping vapor producing the reversal of this line and at the same time giving the H and K lines sharp and bright. The conditions are somewhat similar to those existing on the sun. There we have the H and K lines as the most prominent in the spectrum of the higher layers of the chromosphere, while that of the photosphere and chromosphere combined, as given by the sun's disc, contains λ 4226.9 as very strong.

The density hypothesis is not a new one. Sir William and Lady Huggins found that as they diminished the amount of calcium chloride added to a spark between platinum and iron electrodes, all the lines gradually disappeared leaving at last only the H and K lines. They account for their results as a density effect.

When, however, we consider such remarkable changes as occur in the intensity of the magnesium line λ 4481 with varying amounts of current, the explanation that it is due to temperature or density

[1] *Astrophysical Journal*, 25, 75, 1907.

changes is hardly sufficient, and the suggestion first made by Liveing and Dewar, and developed by Hartmann and Crew, that the cause is electrical in nature, electro-luminescence, seems to have the most weight.

In calcium no lines were found to show such remarkable variations as this magnesium line. The two lines λλ 5189.0 and 4355.4, especially the first, appear to increase their intensity as the current is raised from 0.5 to 5.0 amperes. The line λ 5270.4 remains practically constant in intensity, while the line λ 5189.0 more than doubles its intensity for this range of current-strength.

NEW LINES

The new lines found by Saunders,[1] namely, the triplets beginning at λλ 3876.2 and 3754.2, which were obtained with an arc between copper poles moistened with calcium chloride, and which he says are faint and diffuse, appear very clearly and are quite sharp on the plates of the arc in a vacuum at 12 amperes. The triplet beginning at λ 3678.5 is somewhat diffuse on my plates. Arrangements are now being made to have the wave-lengths of these lines accurately measured by means of a comparison spectrum of iron.

The line λ 3653.6, which Kayser and Runge[2] give with the same intensity as λ 3706.2, does not appear on any of my plates.

It may be interesting to note that the only impurity in the calcium metal was a small trace of magnesium.

DOUBLE REVERSALS

In addition to the large number of plates taken with the arc in a vertical position, i. e., with the discharge perpendicular to the line joining the slit and the arc, others were taken with a right-angled arc. In some cases the positive pole pointed toward the slit, in other cases the negative. It was thought that if double reversals are possible in laboratory sources the right-angled arc with its positive pole facing the slit would be the best method for obtaining it. It somewhat fulfils the conditions existing on the sun, for around the positive pole we have a large mass of dense luminous vapor surrounded by rarer vapor driven off from the negative pole. It was hoped that the

[1] *Astrophysical Journal*, 21, 195, 1905.

[2] *Abhandlungen der K. Preuss. Akad. der Wissenschaften*, 1891.

radiation from this rarer vapor, whether due to temperature or to electrical causes, would be large in intensity. Apparently it was not, for on a careful scrutiny of all the plates obtained with the vertical and right-angled arcs at atmospheric and lower pressures, with large and small currents, not a true double reversal was found.

The lines of the triplet $\lambda\lambda$ 4456.81, 4456.08, 4454.97 show multiple reversal, which is due to the superposition of the first line upon reversals of the last two. The doublet $\lambda\lambda$ 4435.86, 4435.15 gives a splendid illustration of a false double reversal, and is explained in the same way. These reversals are shown in Fig. 2. This is a print from an enlarged positive of the original negative and is therefore a negative; the light portions indicating the reversals.

The distribution of light in the lines produced by the right-angled arc with the positive pole facing the slit as shown in Fig. 3, *a*, is quite different from that produced when the poles are reversed as in Fig. 3, *b*. In the first instance (*a*) the reversals are narrow and sharp, while in the other (*b*) they are broad with very poorly defined edges. When such a difference exists, which depends merely on the orientation of the arc with regard to the slit, the other conditions, such as the current-strength and mean density of the vapor, remaining practically constant, any deductions as to the conditions which exist in sun-spots or faculae from observations upon variations in intensity of arc spectra obtained in the laboratory should include this observation.

An attempt was made to obtain a true double reversal with the calcium arc by the method used by Konen and Hagenbach,[1] when they obtained a multiple reversal of the line λ 2852.25 of magnesium. The method consisted in taking a plate of very short exposure of the arc when it is quickly remade after being extinguished, just as it was on the point of burning. The attempt was not successful.

It may be interesting to note that double reversals can be obtained by exposing the plate first to the arc under heavy currents and then to the same arc under a small current, the result being a composition of a reversal and a bright line. The result is the same as that obtained by Humphreys by placing a small quantity of metallic silver in the arc and exposing the plate long enough to get the effect of both the reversal and the sharp line when the vapor becomes rare.

[1] *Loc. cit.*

Thus, in conclusion, a true double reversal of any of the calcium lines in a laboratory source has not been found. The current-strength was never raised above 20 amperes, and the appearance of the lines with this current in no way indicates that double or multiple reversals would appear with heavier currents.

Bryn Mawr College
January 1908

Minor Contributions and Notes

THE SPECTRA OF ALKALIES[1]

In his dissertation, *Contributions to the Knowledge of the Infra-red Emission Spectra of the Alkalies* (Jena, 1907), Mr. Arno Bergmann published his discovery of a new series in the infra-red portion of the spectra of potassium, rubidium, and caesium, so that in each of these spectra four series are now known. Between these recently discovered series and the first subordinate series there exists a relation similar to that between the principal and the second subordinate series. If we represent by E_1 and E_2 the oscillation frequencies of the termination for both lines of the pairs of the subordinate series, and by E the oscillation frequency at the termination of the new series, the differences E_1-E and E_2-E give very closely the oscillation frequency of the first pair of lines of the first subordinate series.

	Potassium	Rubidium	Caesium
End of the subordinate series as computed by W. Ritz* E_1	21,968.3	20,877.3	19,674.8
E_2	22,024.3	21,115.3	20,227.5
End of the new series as computed by A. Bergmann E	13,482.4	14,344.4	E' 16,791.9 E'' 16,887.7 E 16,839.8 Mean of E' and E''
Distance between the ends E_1-E	8,485.9	6,532.9	2,835.0
E_2-E	8,541.9	6,770.9	3,387.7
Oscillation frequencies of the pair of lines of greatest wave-length in the first subordinate series.......	8,502.0	6,489.3	2,642.3
	8,563.1	6,743.1	3,193.5
	Observed by Bergmann		Not observed, but extrapolated from the series formulae of Ritz, computed by Bergmann

* *Annalen der Physik*, 12, 295, 1903.

The series in the caesium spectrum consists of pairs of lines, and Mr. Bergmann states that in terms of oscillation frequency the two

[1] Translated from advance proofs communicated by the author.

lines of all pairs are equidistant. I should expect that they would draw together toward the end of the series similarly to the pairs of lines of the principal series. More exact investigations may show if this can be the case. The series of potassium and rubidium, also, probably consist of pairs of lines, as Mr. Bergmann remarks. They must be so much closer than the caesium pairs, however, corresponding with the smaller atomic weight of potassium and rubidium, that the dispersion employed hitherto doubtless could not separate them.

If it should be confirmed that the pairs of lines draw together toward the end of the series, I should further suspect that the first subordinate series is connected with the new series in the same manner as the principal series with the second subordinate series. Expressed in the form which W. Ritz has given to the series formulae we should then have:

$$\left.\begin{array}{l}\text{First subordinate series:}\\ \text{Oscillation frequency}\end{array}\right\} = \left\{\begin{array}{l} f(2, \alpha_1, \beta_1) - f(n, \alpha, \beta) \\ f(2, \alpha_2, \beta_2) - f(n, \alpha, \beta)\end{array}\right\} n = 3, 4, 5, \ldots\ldots ,$$

$$\left.\begin{array}{l}\text{New series: Oscillation}\\ \text{frequency}\end{array}\right\} = \left\{\begin{array}{l} f(3, \alpha, \beta) - f(n, \alpha_1, \beta_1) \\ f(3, \alpha, \beta) - f(n, \alpha_2, \beta_2)\end{array}\right\} n = 3, 4, 5, \ldots\ldots ,$$

where

$$f(n, \alpha, \beta) = \frac{109675}{\left(n + \alpha + \frac{\beta}{n^2}\right)^2} .$$

The new series would therefore give, for $n=2$, the oscillation frequency of the principal term of the first subordinate series, only with the negative sign, just as the second subordinate series, for the lowest value of n, gives the oscillation frequencies of the principal term of the principal series also with the negative sign.

In order to confirm these suppositions, we must wait to be sure for more accurate measures of the infra-red lines. The extrapolation of the formulae toward the side of the smaller values of n leaves so much leeway that we cannot state anything with certainty.

Nevertheless, this much is certain, that the new series bears a close relation to the first subordinate series, and that the four series in each of the observed spectra group themselves in pairs. There is a certain symmetry as in reflection, in the circumstance that the principal series ends at a higher oscillation frequency than the subordinate series, while the new series, on the contrary, ends at lower oscillation fre-

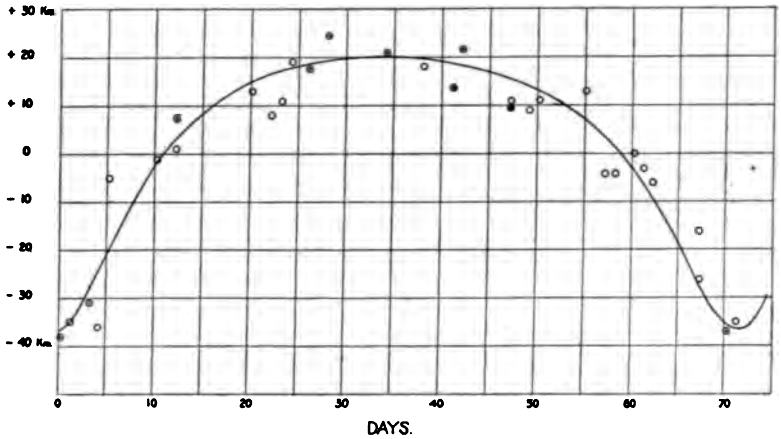
quency; and that the principal term for the one series-pair belongs to the principal series, for the other to the first subordinate series.

CARL RUNGE

GÖTTINGEN
December 1907

η VIRGINIS[1]

Forty-three measurable negatives of this star were obtained between February 22 and July 5, 1907. The first thirty-two negatives were made with the universal spectroscope as adapted for radial-velocity work, the dispersion at $H\gamma$ (λ 4340) being 18.6 tenth-meters per mm. Some five or six were made with the new three-prism spectrograph, whose linear dispersion at λ 4415 is 11.1 tenth-meters per mm. The



Velocity-curve of η *Virginis*.

balance were made with the new single-prism spectrograph whose linear dispersion at λ 4415 is about 32.4 tenth-meters per mm.

In September the last of the plates were measured and approximate values of the elements were obtained from the oscillation curve. Some of the larger residuals are probably due to the low dispersion, as it does not permit of the resolution of the spectral lines of the two components unless they differ in velocity by about 70 km per second. In cases where there was not this difference in velocity the center of intensity of the line would be shifted and an error would, consequently,

[1] Communicated by permission of the Chief Astronomer.

be introduced in the setting. Then, too, there were certain gaps in the curve and, taking all things into consideration, it was felt that more spectrograms would have to be secured before a rigid determination of the elements could be made.

The appearance of Naozo Ichinohe's article in the November number of the *Astrophysical Journal* and the marked similarity of the oscillation curve there given to that obtained here decided us to review the data already secured. Some of the plates where the velocities for the different lines were not in good agreement with one another were re-measured, and a new determination of the elements was made. These differed very slightly from the former determinations; the period of $71^{d}.9$ was accepted instead of my former value of $71^{d}.7$.

The following are the elements for the brighter component, which should be regarded as provisional only:

$P = 71.9$ days.
$e = 0.40$.
$\omega = 185^{\circ}$ measured from ascending node.
Velocity of system $= +2.2$ km per sec.
$T =$ J. D. 2,417,643.50.
$a \sin i = 25,750,000$ km.

W. E. HARPER

DOMINION ASTRONOMICAL OBSERVATORY
Ottawa, Canada
January 1908

SPECTROSCOPIC BINARIES UNDER OBSERVATION AT DIFFERENT INSTITUTIONS

With a view to assist in the avoidance of unnecessary duplication of observations of spectroscopic binaries, the following letter was recently addressed to the spectrographic observers at the principal observatories doing this kind of work. The replies are given in the order in which they were received. It would seem that these lists should be of service as observers are enlarging their programmes. This JOURNAL will be glad to publish any additional data which observers may care to contribute at present or in future for the purpose.

EDWIN B. FROST

YERKES OBSERVATORY, September 16, 1907

DEAR SIR: In the present state of research on the radial velocities of stars, so much remains to be done that it seems important to avoid duplication of work in certain directions, and to secure instead co-operation where feasible. Referring at present only to spectroscopic binaries, it is a matter of common experience that a large number of plates is often required before the period can be determined. This is likely to be wasteful of time, as the same phase may frequently be duplicated and needed phases may not be secured. Now it is decidedly unfortunate to have two different observers unwittingly enter upon the investigation of the spectroscopic orbit of the same star, while so many binaries remain almost untouched.[1] It has, for instance, lately come to my knowledge that an American observer, in starting upon radial velocity work, selected a spectroscopic binary for investigation which has been for a long time under observation by a European astronomer, who had nearly completed his determination of the orbit. The American had no means of knowing, however, that the investigation of that particular star had been undertaken in Europe. An unnecessary number of plates has thus accumulated, which could far better have been obtained for two different stars, as the orbit by either observer would doubtless be amply accurate for present needs.

The remedy that I would suggest is that observers beginning systematic observations of particular stars to get data for determining their spectroscopic orbits should in some manner communicate the fact to their fellow-workers in this field. The *Astrophysical Journal* might appropriately be made the medium for such inter-communications.

A second important advantage of this plan, if adopted, would doubtless soon be apparent. Observers who had casual spectrograms of a star stated to be under investigation by some other astronomer would doubtless be glad to communicate their results promptly, either by publication or privately, so that the investigation might be greatly expedited, the period determined much more accurately, and observations at important phases obtained which otherwise might not be utilized.

I would therefore inquire if you would care to communicate to the *Astrophysical Journal* a statement of the spectroscopic binaries now under investigation at your observatory or likely to be taken up within the next year. I shall of course be glad to make a statement of this sort for the Yerkes Observatory.

Very truly yours,

EDWIN B. FROST

HARVARD COLLEGE OBSERVATORY, September 21, 1907

The only spectroscopic binaries likely to be investigated at the Harvard College Observatory are those of Class A, in which both components are bright. They have been photographed here for many years, and the plates obtained will permit a very precise determination of their periods. No investigations of spectroscopic binaries of Class B, in which only one component is bright, are contemplated here at present.

EDWARD C. PICKERING

[1] It is probable that orbital investigations have been made for not over one-fifth of the spectroscopic binaries at present known.

MOUNT HAMILTON, September 23, 1907

The orbits of the following spectroscopic binary stars are under investigation at the Lick Observatory:

α Ursae Minoris (Polaris)	*SU Cygni*
δ Cephei	*U Aquilae*
X Sagittarii	*S Sagittae*
β Capricorni	*R Lyrae*
β Herculis	*l Carinae*
κ Pegasi	

It is not our purpose to undertake investigations of spectroscopic binary stars discovered at other observatories except in case of a variable star which may be necessary to round out researches that we have undertaken on other related variable stars.

W. W. CAMPBELL

DOMINION OBSERVATORY, OTTAWA, September 27, 1907

Binaries of which several plates have been measured:

o Andromedae	*θ Aquilae*
η Virginis	*α Coronae Borealis*
η Boötis	*τ Tauri*
ι Orionis	*B.D.* $-1^\circ 1004$
ψ Orionis	*ε Herculis* } Not many of these
ν Orionis	*δ Aquilae* }
γ Geminorum	

A few plates only:

η Geminorum	*d Boötis*	*o Leonis*

Proposed for the next year.

h Draconis	*ε Ursae Minoris*

J. S. PLASKETT

POULKOVO, October 3, 1907

(Extract)

I am quite in accord with your suggestion that the spectroscopic binaries should be distributed among the different observatories; but I do not expect to be able to accomplish much in this direction under our climatic conditions. I might perhaps observe the brighter stars, not fainter than the fifth magnitude, such as:

δ Cephei	*δ Orionis*
ζ Geminorum	*ι Pegasi*
λ Tauri	*η Pegasi*
η Aquilae	etc.

We lack a suitable spectrograph, or rather a thermostat, for observing stars fainter than magnitude 4½. In any case I shall be glad to take part in this work as far as possible.

I inclose a small list of our plates of such stars which have not yet been measured:

	Polaris	*α′ Geminorum*	*α″ Geminorum*	*ζ Ursae Majoris*	*δ Cephei*	*β Lyrae*
1900	36	..	..	..	..	..
1902	..	4	1	..	9	2
1903	..	26	2	..	13	19
1904	..	2	..	..	6	9
1905	16	11	6	16	2	10
1906	21	3	..	..	..	3
1907	..	3	8	..	..	..

From 1893 to 1907 (March) 2347 spectrograms have been obtained at Poulkovo, of which about 1200 have been measured and reduced, leaving 1100 which are not yet worked up.

A. Belopolsky

Potsdam, October 7, 1907

(Extract)

I am glad to communicate my list of stars. I have thoroughly worked up:

Polaris, β Persei, α Coronae, δ Orionis.

I have similarly followed a few other stars, but just now will refrain from making out a complete list, as I shall very soon refer to the matter more fully.

It would not be a misfortune at present, when spectrographic measurements are in the stage of development, to have the same piece of work carried out by several observers. We thus obtain a good check on the absolute correctness of the results.

J. Hartmann

Royal Observatory, Cape of Good Hope, October 31, 1907

I heartily concur with your letter of September 17 as regards the undesirability of duplication of work in determining the orbits of spectroscopic binaries while so much remains to be done.

The study of these binaries has not hitherto formed part of our programme. I inclose, however, a list of stars of which we already have spectrograms and am quite willing that this should be published as you suggest. This list is subdivided under two headings, the first group containing those stars with spectra suitable for accurate line-of-sight determinations, the second those with lines too diffuse for exact measurement or in other ways unsuitable.

The list, which will also form the basis of our programme for the next year, has been prepared with a view to the determination of radial velocities, and more especially the epochs of observations have been selected so as to furnish as strong a determination as possible of the Solar Parallax.

For these purposes any information relating to the orbital velocities of such binaries as may be included in the list would be of the highest value to us, and in return for the same I should be happy to place at the disposal of other observers, in advance of publication, any information which I am able to furnish regarding special stars contained in the list for which I may receive application.

S. S. Hough

STARS OF WHICH SPECTROGRAMS HAVE BEEN ALREADY SECURED AT THE CAPE

BRIGHT STARS SUITABLE FOR VELOCITY DETERMINATIONS

α *Argus*	β *Geminorum*
ι *Argus*	γ *Geminorum*
α *Arietis*	β *Gruis*
α *Boötis*	α *Hydrae*
α *Canis Majoris*	α *Orionis*
δ *Canis Majoris*	α *Phoenicis*
α *Canis Minoris*	α *Scorpii*
α_2 *Centauri*	ε *Scorpii*
α_1 *Centauri*	α *Tauri*
γ *Crucis*	α *Trianguli Australis*

BRIGHT STARS UNSUITABLE FOR VELOCITY DETERMINATIONS

γ *Argus*	ε *Sagittarii*
δ *Capricorni*	δ *Scorpii*
β *Centauri*	θ *Scorpii*
α *Eridani*	λ *Scorpii*
β *Leonis*	α *Virginis*
ε *Orionis*	β *Argus*
α *Piscis Australis*	ε *Argus*

ALLEGHENY OBSERVATORY, December 16, 1907

(Extract)

I had not intended to let so long a time go by without complying with your circular request for our observing list of binaries. As you already know, I am heartily in favor of the proposal, and I look forward to seeing the programmes of other observers with much interest. I do not think it would much harm if several typical orbits were duplicated, however, and for this reason I intend to finish those stars that we have already well under way. In the case of other stars I will be glad to furnish velocities to other observers where they may be needed.

Our observing list includes (1) all the *Algol* variables that are within our reach:

β *Persei*	*U Ophiuchi*
λ *Tauri*	*U Sagittae*
R Canis Majoris	β *Lyrae*
δ *Librae*	

and as many more as experience may indicate that we can profitably attack; (2) binaries whose spectra are such that they may best be observed with low dispersion:

α Andromedae	*ε Herculis*
π Andromedae	*δ Aquilae*
ε Ursae Majoris	*θ Aquilae*
α Virginis	*6 Lacertae*
α Coronae Borealis	*o Andromedae*

Needless to say we shall add to this list from time to time.

FRANK SCHLESINGER

LOWELL OBSERVATORY, January 12, 1908

In response to your circular letter suggesting to radial-velocity observers a system of intercommunication which should advance the study of the orbits of spectroscopic binary stars and at the same time should avoid the present unnecessary duplication of observations, I am glad to submit the following list of such stars which we are observing here with a view to determining their orbits:

α Librae	*λ Scorpii*
β Scorpii	*δ Capricorni*
σ Scorpii	*ε Capricorni*

We had been observing also *α Andromedae* as opportunity afforded and have a fair series of plates,[1] but inasmuch as a provisional orbit has now been determined for this star—by Dr. Ludendorff, at Potsdam (*A. N.*, 4220)—we shall want to give the time to other stars. It is to be hoped all velocity observers will respond to your proposal in order that all may work more efficiently. To provide some system for the newly discovered star would it not be well for any observer wishing to undertake the orbit to communicate with the discoverer?

V. M. SLIPHER

YERKES OBSERVATORY, January 20, 1908

The list of spectroscopic binaries now under especial observation here is as follows. We should ordinarily include on our programme only such stars as were detected here.

13 Ceti	*β Lyrae*
δ Ceti	*ε¹ Lyrae*
ν Eridani	*τ Cygni*
9 Camelopardi	*β Equulei*
π⁵ Orionis	*ζ Ursae Majoris, seq.*
μ Orionis	*Alcor*

The last five have recently been detected here.

EDWIN B. FROST

[1] The measures of those plates will be completed and made public in the near future only in case they are wished for use in investigating the orbit.

OBSERVATORY, CAMBRIDGE, February, 1908

Our work during the last two years has been more concentrated on solar work than on stellar observations. The four-prism stellar spectrograph is dismounted, and no new material suitable for exact determinations of velocity has been collected. Experiments are now being carried out with a grating spectrograph in photographing the red end of star spectra. I intend to carry these through before fitting the four-prism spectrograph with some form of temperature control.

Meanwhile, as for binaries, we have measurements of the following, for discussion:

α *Canis Majoris*	ζ *Herculis*
α *Canis Minoris*	α_1 and α_2 *Geminorum*

H. F. NEWALL

BONN, February 8, 1908

Extended series of observations of spectroscopic binaries for the purpose of accurate orbital determinations have been made here recently only of α *Aurigae* and ι *Pegasi*. The results of these investigations will be published presently.

Isolated spectrograms have been made here, however, of a large number of spectroscopic binaries. I cite the following, with the number of plates of each star:

α *Ursae Minoris*	5	χ *Draconis*	5
f Tauri	3	*31 Cygni*	4
μ *Ursae Majoris*	5	ε *Cygni*	6
η *Boötis*	6	ζ *Cygni*	4
β *Herculis*	5	ζ *Cephei*	4
ζ *Herculis*	5	η *Pegasi*	4
λ *Andromedae*	4		

These plates have been already measured and reduced. I hope to be able to publish the results in the not distant future, in connection with an extensive series of radial velocities which we have determined at Bonn during the last four years.

F. KÜSTNER

HARVARD COLLEGE OBSERVATORY, January 31, 1908

The compilation, by Professor Frost, of current observations of spectroscopic binaries suggests many important investigations, some of which are proposed below:

1. In the case of variable stars, especially those of short period, photometric observations should be made, as nearly as possible at the same time as the spectra are photographed. The Harvard Observatory is ready to undertake such observations if notified when the photographs are likely to be made.

2. There are several stars, like *S Monocerotis* and *Y Aquilae,* whose variability has been announced and confirmed, and whose designations have been

assigned to them as variables, but which show no variation at the present time, from careful measurements. (See *Harvard Annals*, 55, 69.) It is possible that these may be *Algol*-stars of long period, or may have a period of almost exactly one or more days. Such a variation could not now readily be determined photometrically. These stars prove to be spectroscopic binaries, and photographs of their spectra, taken at any time, should show when the relative motion is zero, and when an eclipse or diminution in light is, therefore, probable.

3. The spectroscopic binaries *V Puppis* and μ^1 *Scorpii* have a range of motion of several hundred kilometers. Therefore, the exact form of their orbits should be determinable with a high degree of precision.

4. The star ζ *Ursae Majoris* (*Mizar*) is bright enough to be photographed with small instruments. A study of its variations with a slit-spectroscope would have great value. A large number of early photographs, taken at Harvard with an objective-prism, showed marked irregularities. No similar irregularities appeared in the photographs of β *Aurigae*, the only other star of this class then known. The investigation was abandoned owing to the difficulty when an objective-prism is used in distinguishing between a true doubling and that due to a change in focus of the principal telescope.

EDWARD C. PICKERING

POTSDAM, February 26, 1908

(*Extract*)

Professor Evershed and I are at present making extended series of observations with Spectrograph IV attached to the 32.5-cm refractor of the following spectroscopic binaries:

α *Andromedae*	β *Ursae Majoris*
β *Arietis*	ϵ *Ursae Majoris*
ϵ *Aurigae*	ω *Ursae Majoris*
γ *Geminorum*	δ *Aquilae*

With a few exceptions I have measured all the plates so far obtained of these stars. Elements of the orbit of β *Arietis* I have already published, and I shall probably soon be able to communicate preliminary elements for γ *Geminorum*. The series of observations of α *Andromedae* and ϵ *Ursae Majoris* presumably can soon be concluded. Although we have already obtained 60 plates of ϵ *Aurigae*, the star needs to be followed longer. This is also true of β *Ursae Majoris*, ω *Ursae Majoris*, and δ *Aquilae;* of the last two we so far have only a few plates.

H. LUDENDORFF

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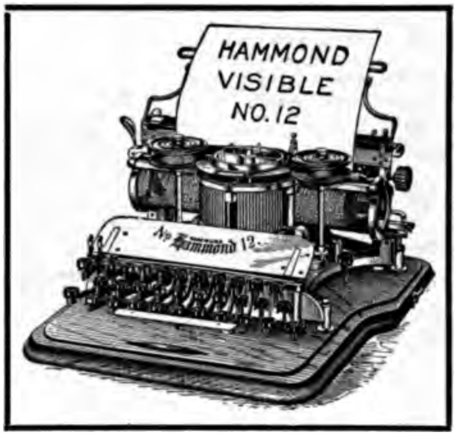
Model  **No. 12**

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VOLUME XXVII NUMBER 3

THE ASTROPHYSICAL JOURNAL

An International Review of Spectroscopy and Astronomical Physics

APRIL 1908

CONTENTS

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OF ALL SCENTED SOAPS PEARS' OTTO OF ROSE IS THE BEST.

THE

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AND ASTRONOMICAL PHYSICS

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THE PHOTOGRAPHIC DETERMINATION OF STAR-COLORS AND THEIR RELATION TO SPECTRAL TYPE

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It has long been recognized that eye estimates form a very unsatisfactory method of determining star-colors, and an urgent need has been felt of some means of accurate measurement. The plan we are following seems to supply that need, and also aids in the solution of two very interesting problems. First, it enables us to co-ordinate visual and photographic magnitudes, thus allowing us to use as standards the visual magnitudes of the white stars from the best modern photometric catalogues, and at the same time avoid many of the inherent difficulties and systematic errors of visual measures of colored stars. Second, important data are added for the study of stellar evolution, since the relation of color to the stages of stellar development is very close and capable of quite precise determination.

Our method is based on a suggestion first made (as far as we are aware) by Schwarzschild, that the difference between the visual magnitude of a star and that obtained from ordinary photographic plates, would give an accurate measure of the star's color. He called this difference the "Farbentönung."[1] Our addition consists in determining the "visual" magnitudes also by photographic means and making both determinations practically simultaneous. With this in view, pairs of ordinary and isochromatic plates were taken regu-

[1] *Sitzungsberichte der kaiserl. Akademie der Wissenschaften in Wien. Mathem.-naturw. Classe*, 109, 1127, 1900.

larly from 1904 to 1906 with the 24-inch reflecting telescope of this observatory, and a method was suggested of deriving the "visual" magnitudes from the isochromatic plates.[1]

In 1906, Mr. R. J. Wallace, of this observatory, prepared a "visual luminosity filter" which greatly increased the convenience and accuracy of the work, for by using it on the reflecting telescope with properly sensitized plates it is true to its name and gives visual magnitudes of colored stars without any correction.

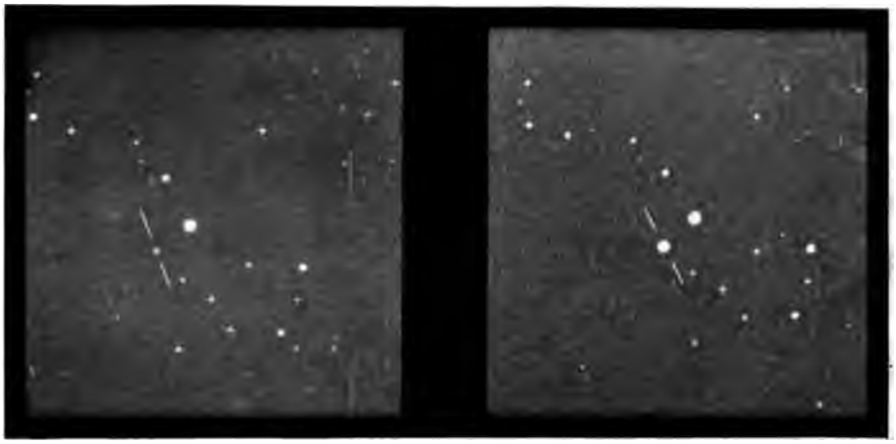
A striking example of the advantages of this filter is shown in Plate XI, Figs. 1 and 2, giving the field around the red star *U Cygni*. These figures are reproduced by permission from Mr. Wallace's paper[2] in which he describes in detail the method of preparing the filter. Fig. 1 shows the red star (identified by the two short lines) very faint, while Fig. 2, taken with the bathed plate and filter, shows it about equal to the neighboring solar-type star which is *B.D.* $+47°3078$. On the evening we took these plates, October 3, 1906, visual comparisons were made of these two stars by Jordan, Wallace, and Parkhurst, with a low-power ocular on the 24-inch reflector, and all agreed in considering them about equal. On the Seed plate, however, the red star is 4.0 magnitudes fainter than its neighbor. We find, therefore, that the combination of filter, Cramer Trichromatic plate, and reflecting telescope gives visual magnitudes for stars as red as *U Cygni*, whose color is given as 9.3 on Chandler's decimal scale. It will be shown later that stars of less intense color are also properly represented.

Fig. 4 (drawn from the data in Mr. Wallace's paper) shows the curves of sensitiveness to daylight of the Seed and Trichromatic plates, the former without, the latter with, the filter. The point of maximum sensitiveness of the Trichromatic plate is near λ 5550, but the lower part of the curve extends farther toward the blue than the red, so that the center of gravity of the curve is at λ 5325. The center of gravity of the curve for the Seed plate is at λ 4275. These curves explain in a very satisfactory manner the reason why the red star appears in its true brightness on the Trichromatic plate. It is evident that a star whose maximum radiation is in the blue or violet will give

[1] *Science*, 21, 417, 1905.

[2] *Astrophysical Journal*, 24, 269, 1906.

PLATE XI



U Cygni

FIG. 1.—On Seed "27" plate, without filter. FIG. 2.—On Cramer "Trichromatic," with filter

COLOR-EFFECT OF RED STAR

11 Sagittae

18 Leonis

S Sagittae

19 Leonis

R Leonis

FIG. 3.—SPECTRAL TYPES WITH OBJECTIVE-PRISM

a stronger image on the Seed plate, while one whose maximum is in the yellow or red will appear stronger on the Trichromatic plate. The more intense the color of the star, the greater will be the difference of magnitude on the two plates, thus giving a measure of color-intensity as accurate as the measure of magnitude.

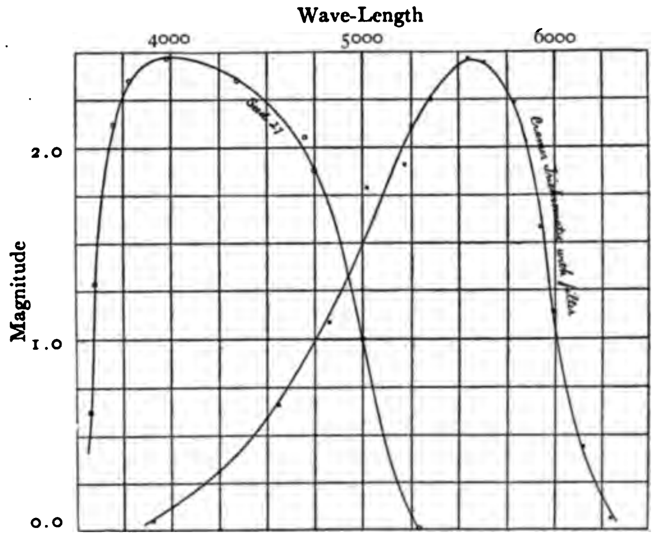


FIG. 4.—Spectral Intensity-Curves.
Seed, and Trichromatic with Filter.

The magnitudes are obtained from these plates by measuring the disk-diameters under the microscope and reducing by means of the formula:

$$\text{Mag.} = a - b\sqrt{D}\,,$$

where D is the disk-diameter, a is a constant for each plate depending on the exposure, while b depends on the emulsion, and the conditions of development which are kept constant in agent, time, and temperature. With the standard development, ten minutes in hydroquinone at 20° C., the value of b was found to be 0.94 for the Seed and 0.77 for the Trichromatic and Pan-iso plates, when the unit of diameter is 0.001 mm. These values were obtained from the Potsdam magnitudes of white stars in the Pleiades group. The value of a is found for each plate by using visual magnitudes of white stars.

About 400 color pairs were taken on Seed and Trichromatic plates

by Jordan between October 1906 and June 1907: but as the Trichromatic required nine times the exposure of the Seed, a faster plate was needed. This was supplied by Mr. Wallace in June 1907 in his new Pan-iso plate, bathed with pinacyanol, pinaverdol, and homocol. A full description of this plate has been recently published by Wallace in this journal.[1]

With the filter this plate requires five times the exposure of the Seed plate, a decided gain over the Trichromatic. Comparisons in the same star fields showed that the two plates give practically the same color-intensity for both yellow and red stars, and this is confirmed by the curves of sensitiveness to spectral light, shown in Fig. 5. The plates for this figure were exposed to daylight in a spectroscope provided with a Wallace grating replica, therefore the spectrum is normal. They had the standard development as given above. The intensity of the light action was measured in a Hartmann surface photometer whose wedge is so calibrated as to give directly the relative intensity of the light striking the plate, expressed in stellar magnitudes.[2] The conditions of development and measurement are therefore the same as for the stellar plates. A comparison of Figs. 4 and 5 will show:

1. The curves for the Seed plates differ slightly at the maximum; still the center of gravity, representing the integrated effect of the light, is near λ 4275 in each case.

2. In like manner the curves for the Trichromatic and Pan-iso plates differ in the wave-length of the point of maximum, but the center of gravity of each lies near λ 5325.

3. As a result, the two combinations should yield similar color-differences, as they were found by trial to do.

There remains for consideration the very important question—Does this combination of plate and filter give visual magnitude-values for stars of different colors? The curves shown might suggest a negative answer to this question, unless the effect of the Purkinje phenomenon were considered. The position of the visual maximum in the spectrum, is variously stated by different authorities from wave-lengths 5500 to 5900, but it is well known that this maximum

[1] "Studies in Sensitometry. II," *Astrophysical Journal*, 26, 317, Fig. 7, 1907.

[2] "An Absolute Scale of Photographic Magnitudes," *Astrophysical Journal*, 26, 244, 1907.

shifts toward the blue with decreasing intensity of illumination. Abney[1] gives it as about λ 5300 in faint light. In order to make a definite statement of the position of visual maximum it is necessary, therefore, to state the intensity of illumination, the personal equation of the observer's eye, and if for telescopic work, the transparency of the air. In practice it is next to impossible to make these statements definite, but this amounts to saying that the "visual" magnitude of a colored star can hardly be definitely stated, a fact that is now recog-

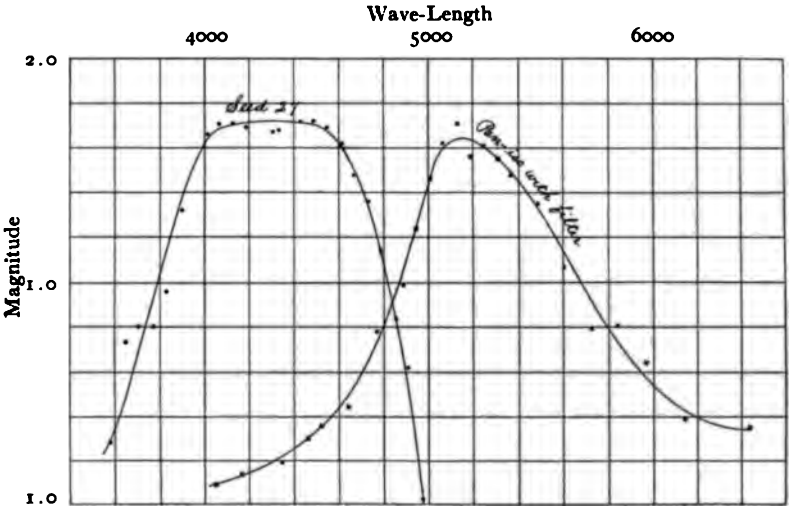


FIG. 5.—Spectral Intensity-Curves. Seed, and Pan-iso with Filter.

nized by photometric workers. The photograph then can agree only with some particular visual scale for colored stars at a single magnitude with some particular aperture. It will be shown on page 175 that it agrees with the Potsdam scale at 6.0 magnitude, with 135 mm (5.3 inches) aperture, the standard aperture to which the Potsdam magnitudes were referred.

Tables I and II show in detail the comparison between our "visual" magnitudes, derived from the Pan-iso plates, and those taken from the Potsdam *Photometric Durchmusterung*. In Table I the stars are arranged in order of magnitude, so that corrections can be applied for the Purkinje phenomenon. The first four columns give the *B. D.*

[1] *Color Vision*, p. 103.

TABLE I

COMPARISON OF PAN-ISO WITH POTSDAM MAGNITUDES OF COLORED STARS

STAR *B. D.*	UNCORRECTED MAGNITUDES			MEANS		CORRECTED MAGNITUDES			
	P−i.	*P.DM.*	Δ Mag.	*P.DM.* Mag.	Δ Mag. *P−i.* −*P. DM.*	Correction	Corr'ted *P. DM.*	Δ Mag.	Mean Δ Mag.
+47° 843	4.61	4.52	+0.09			+0.16	4.68	−0.07	
+34 4079	4.86	4.79	+ .07			+ .13	4.92	− .06	
+49 656	5.14	4.83	+ .31			+ .14	4.97	+ .17	
+38 3780	5.21	5.16	+ .05			+ .10	5.26	− .05	
+19 401c	5.37	5.27	+ .10			+ .08	5.35	+ .02	
+49 649	5.70	5.44	+ .26	5.43	+0.04	+ .07	5.51	+ .19	−0.03
+58 2201	5.72	5.59	+ .13			+ .05	5.64	+ .08	
+19 4015	5.92	5.88	+ .04			+ .02	5.90	+ 02	
+47 844	6.03	6 04	− .01			.00	6.04	− .01	
+19 4017	5.81	6.04	− .23			− .01	6.05	− .24	
+44 261	5.85	6.22	− .37			− .01	6.21	− .37	
+38 3772	6.16	6.24	− .08			− .01	6.23	+ .07	
+36 3744	6.43	6.32	+ .11			− .02	6.30	+ .13	
+35 4141	6.37	6.38	− .01			− .02	6.36	+ .01	
+49 666	6.23	6.40	− .17			− .03	6.37	− .14	
+47 2937	6.18	6.42	− .24	6.58	−0.03	− .03	6.39	− .21	+0.02
+36 3820	6.51	6.42	+ .09			− .03	6.39	+ .12	
+33 3910	6.71	6.70	+ .01			− .06	6.64	+ .07	
+33 3938	6.76	6.80	− .04			− .06	6.74	+ .02	
+36 3807	6.98	7.06	− .08			− .09	6.97	+ .01	
+15 1191	7.39	7.27	+ .12			− .11	7.16	+ .23	
+19 4004	7.11	7.37	− .26			− .12	7.25	− .14	
+57 2322	7.26	7.36	− .10			− .12	7.24	+ .02	
+34 4111	7.04	7.06	− .02			− .09	6.97	+ .07	
+36 3880	7.36	7.34	+ .02			− .12	7.22	+ .14	
+48 3137	7.06	7.39	− .33	7.51	−0.13	− .12	7.27	− .21	0 00
+35 3962	7.32	7.40	− .08			− .12	7.28	+ .04	
+34 4114	7.28	7.44	− .16			− .12	7.32	− .04	
+35 4219	7.56	7.69	− .13			− .16	7.53	− .09	
+58 790	7.72	7.80	− .08			− .16	7.64	+ .08	
+58 2195	7.98	8.10	− .12			− .21	7.89	+ .09	
	Means		±0.13					±0.10	

number of the star, the magnitudes on the two systems, and the differences, in the sense, Pan-iso minus *P. DM.* The systematic character of the differences in column four is evident at a glance, and is still plainer in the means taken in columns five and six. It seems reasonable to ascribe these differences to the physiological effect on the visual measures arising from the decreasing brightness of the stars, therefore corrections to the *P. DM.* magnitudes are derived graphically from the means in columns five and six, and arranged in column seven. Columns eight and nine give the corrected *P. DM.* magnitudes and

the corrected differences, which are no longer systematic as shown by the means in the last column. The last line of the table shows that the accidental differences between the two systems are reduced from ±0.13 to ±0.10 by the correction.

Two important deductions can be made from Table I. First, the two systems of "visual" magnitudes, derived from the plate and the Potsdam catalogue, agree in their color-perception at magnitude 6.0. Second, the plate gives correct visual magnitudes of colored stars (see color-intensities of these stars in Table II), which has usually been considered as impossible.[1]

TABLE II

COMPARISON OF PAN-ISO AND *P. DM.* MAGNITUDES IN ORDER OF COLOR-INTENSITY

STAR *B. D.*	COLOR-INTENSITY	PAN-ISO MAG.	CORRECTED *P. DM.* MAG.	Δ MAG. *P-i.* −*P. DM.*	MEANS	
					Color.	Δ Mag.
+19° 4015	0.00	5.92	5.88	+0.04		
+36 3880	.03	7.36	7.34	+ .03		
+47 844	.10	6.03	6.04	− .01		
+58 2195	.13	7.98	7.89	+ .09		
+19 4004	.36	7.11	7.25	− .14	0.32	−0.01
+33 3910	.49	6.71	6.64	+ .07		
+35 4141	.49	6.37	6.36	+ .01		
+57 2322	.51	7.26	7.24	+ .02		
+47 2937	.52	6.18	6.39	− .21		
+49 666	.55	6.23	6.37	− .14		
+33 3938	.62	6.76	6.74	+ .02		
+34 4114	.69	7.28	7.32	− .04		
+35 4219	.70	7.56	7.53	+ .03		
+58 790	.82	7.72	7.64	+ .08		
+38 3772	.84	6.16	6.23	− .07	0.91	+0.05
+19 4010	.97	5.37	5.35	+ .02		
+36 3807	1.04	6.98	6.97	+ .01		
+15 1191	1.13	7.39	7.16	+ .23		
+36 3820	1.14	6.51	6.39	+ .12		
+34 4111	1.16	7.04	6.97	+ .07		
+35 3962	1.23	7.32	7.28	+ .04		
+47 843	1.23	4.61	4.68	− .07		
+49 649	1.28	5.70	5.51	+ .19		
+48 3137	1.29	7.06	7.27	− .21		
+36 3744	1.35	6.43	6.30	+ .13	1.42	−0.05
+34 4079	1.45	4.86	4.92	− .06		
+44 261	1.45	5.85	6.21	− .36		
+38 3780	1.60	5.21	5.26	− .05		
+19 4017	1.65	5.81	6.05	− .24		
+49 656	1.94	5.14	4.97	+ .17		

[1] See, for example, Scheiner, *Die Photographie der Gestirne*, p. 238.

In Table II the data for the same stars are arranged in order of color-intensity. The last column shows that there is little or no systematic difference between the magnitudes of the two systems, depending on intensity of color. The second column, color-intensity, is taken from Table III, except for the four stars, +19°.4015, +36°.3880, +47°.844, and +49°.656. As these stars did not have satisfactory spectra on the objective prism plates they were not included in Table III, but their color-intensities were derived in the same manner as were those of the remaining stars.

There remains to be considered the relation between the color-intensities, as above deduced, and the spectral types of the stars. To obtain the latter we were fortunate in having at our disposal an excellent objective prism, by Zeiss, of 145 mm aperture and 15° angle, fitted to a doublet lens of the same aperture and made by the same firm. The focal length of the lens is 814 mm and the resulting spectra have a dispersion of 2.7 mm between the Fraunhofer lines F and K. In spite of this small scale the definition is so good that the spectral types of stars brighter than magnitude 9 can be readily seen on plates of one hour exposure or less.

Although the scale of these spectra is rather small for satisfactory reproduction, Fig. 3 of Plate XI will give an idea of the appearance of the different types. It is a composite negative, made from objective-prism plates 34 and 84, of the fields around *R Leonis* and *S Sagittae*, respectively. The upper spectrum, that of *11 Sagittae*, is a good example of the type chosen for magnitude standards. On this scale such spectra show only the absorption lines of the principal hydrogen series. Fortunately for our purpose spectra of this type are at once the most numerous and the easiest to distinguish. For the work in hand it was decided to use the spectral classification of the *Draper Catalogue*, as explained and illustrated by Miss Maury and Miss Cannon,[1] using the letters A, F, G, K, and M with the following meaning:

A, White or hydrogen stars as explained above.

F, In addition to the hydrogen lines the Fraunhofer K is about as strong as $H\delta$.

G, The only prominent lines in the spectrum are K, H, and G.

[1] *Annals of the Harvard College Observatory*, 28.

K, Stars like *a Tauri* showing K, H, and the calcium line λ 4226.9 as the only prominent lines.

M, Spectra showing the above three lines and the characteristic flutings of Secchi's Type III, like *ρ Persei*.

Forms intermediate between the above classes are indicated by tenths of the interval between the letters. Between A and F the criterion used is the relative strength of the Fraunhofer K and $H\delta$. Between F and G we use the relative strength of the solar G group and the $H\gamma$ line. Between G and K the solar G and the calcium line λ 4226.9 are compared. Between K and M the increasing strength of the flutings is noted. For the present paper we have used no stars farther advanced than K 5 M, since many of the stars classed as M are variables of long period. We have been able to confirm the opinions expressed by some visual observers that the color of a long-period variable becomes more intense near minimum. Such stars are therefore not adapted for our present purpose and are excluded.

With these explanations we return to the consideration of Fig. 3. The spectrum of *19 Leonis* evidently lies between A and F, since the K line has rather more than half the intensity of $H\delta$. The spectrum of *S Sagittae* (a variable of short period) lies between F and G, nearer to G since the G group is stronger than $H\gamma$. The spectrum of *18 Leonis* lies between G and K, nearer to G as the G group is stronger than λ 4226.9. *R Leonis* is a fine example of M with the hydrogen lines bright. This kind is called Md in the later Harvard publications.

With these explanations we are ready to compare our results for color and spectral type. The data for forty-nine stars are given in detail in Table III. The color-intensity, given in column four, is the difference in magnitude between the Seed, and Pan-iso plates. For four stars in one field, mentioned in the footnote, this magnitude difference is increased by 0.07, since the standard stars are not pure white but have the mean color 0.07. In the fifth column the spectra are given on the above classification, except that the first two are Wolf-Rayet stars. It is interesting to note that these stars are practically white. These colors and spectral types are platted in Fig. 6 with color-intensities as abscissas and types as ordinates on an arbitrary scale, allowing equal distances between the letters. The last two

TABLE III

COMPARISON OF COLORS AND SPECTRA

Star B.D.	Magnitudes		Δ Mag. Color	Spectrum	Residuals	
	Seed	Pan-iso			Color	Spectrum
+35°4013	7.95	7.93	0.02	W-R	....	..
+35 4001	7.94	7.91	.03	W-R	....	.
+58 2193*	7.99	8.03	.03	A 1 F	0.02	0
+58 2187*	7.13	7.08	.12	A 5 F	.12	2
+58 2195*	8.04	7.98	.13	A 2 F	.03	1
+35 3988	9.06	8.83	.23	A1-2F	.15	3
+48 2943	9.08	8.75	.33	A 8 F	.05	1
+19 4004	7.47	7.11	.36	A3-4F	.12	4
+48 2934	8.62	8.25	.37	A 8 F	.01	0
+37 3787	9.40	9.02	.38	F	.10	2
+33 3910	7.20	6.71	.49	F	.01	0
+35 4141	6.94	6.37	.49	F 2 G	.09	2
+35 3966	8.71	8.20	.51	F?	.03	1
+57 2322	7.77	7.26	.51	F 5 G?	.21?	5?
+47 2937	6.70	6.18	.52	F 1 G	.03	1
+36 3735	8.82	8.29	.53	F?	.05	1
+49 666	6.78	6.23	.55	F 1 G	.03	0
+33 3938	7.38	6.76	.62	F	.14	2
+37 3781	8.38	7.80	58	F 2 G	.00	0
+34 4114	7.96	7.28	.69	F 2 G	.11	1
+35 3844	9.06	8.36	.70	F 5 G	.02	0
+35 4219	8.26	7.56	.70	F 5 G	.01	0
+58 790	8.54	7.72	.82	G-	.04	1
+38 3772	7.00	6.16	.84	G	.15	3
+48 2933	9.26	8.36	.90	F 8 G	00	0
+38 3915	9.16	8.23	.93	G	.06	1
+27 3411	4.66	3.70	.97	G	.02	0
+19 4010	6.34	5.37	.97	G	.02	0
+36 3807	8.02	6.98	1.04	G	.05	1
+15 1191	8.52	7.39	1.13	G 2 K	.03	1
+36 3820	7.65	6.51	1.14	G 2 K	.04	1
+34 4111	8.20	7.04	1.16	G1-2K	.10	1
+58 2201*	6.81	5 72	1.16	K-	.23	4
+35 3954	9.14	7.96	1.18	G2-3K	.06	1
+58 787	9.43	8.22	1.21	G-K	.04	1
+35 3962	8.55	7.32	1 23	G-K	.02	0
+47 843	5.84	4.61	1.23	K-	.16	3
+49 649	6.98	5.70	1.28	G-K	.03	0
+48 3137	8.35	7.06	1.29	G-K	.04	0
+57 2323	9.35	8.02	1.33	G-K	.08	2
+38 3836	8.93	7.60	1.33	G-K	.08	2
+36 3744	7.78	6.43	1.35	G-K	.10	2
+35 3985	8.43	7.06	1.37	K	.18	3
+34 4079	6.31	4.86	1.45	K	.10	2
+44 261	7.32	5.85	1.45	K	.10	2
+38 3780	6.81	5.21	1.60	K	.07	1
+19 4017	7.46	5.81	1.65	K	.12	2
+37 3698	8.92	7.09	1.83	K-M	.00	0
+36 3892	9.60	7.74	1.86	K-M	.00	0
				Means	±0.07	1

* The spectra of the two standard stars in this field are A 1 F and A 2 F, respectively. The mean color-intensity corresponding to these spectra, as derived from the curve, is 0.07, therefore the differences of magnitudes between the Seed and Pan-iso plates were increased by that amount.

columns in Table III give the distances between the platted points and the smooth curve. The horizontal distances give color-residuals in magnitudes, the mean being ±0.07. For the vertical residuals the unit is one-tenth the distance between adjacent letters, the mean being one of these units. The moderate size of these residuals, over a wide range of spectral types and colors, shows that the method is fairly accurate. As far as we can judge from the limited number of

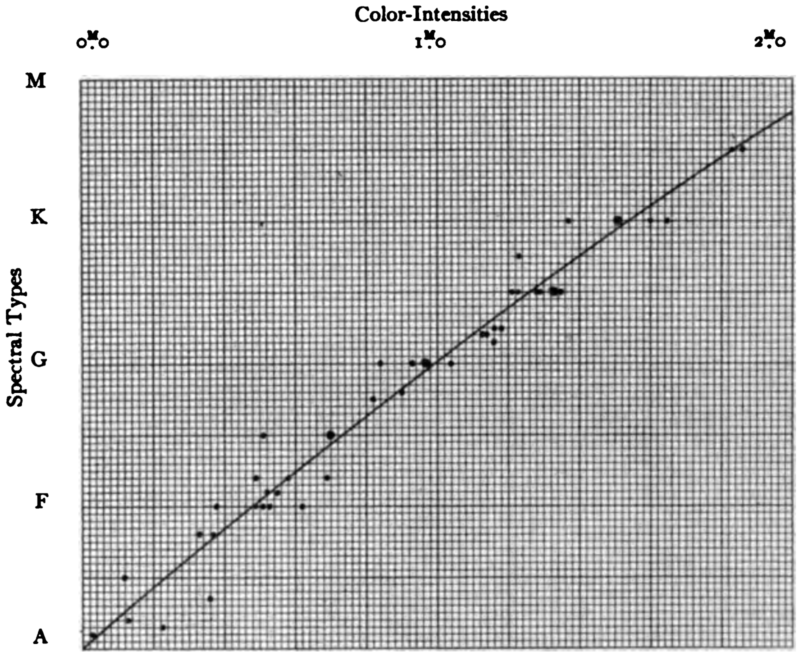


FIG. 6.—Star Spectra and Colors.

points platted, the scale of ordinates, representing the interval between the spectral types, should increase upwards, instead of being uniform. The important conclusion is that color-intensities can be measured by this method as accurately as star-magnitudes; also that definite color-intensities correspond in general to definite spectral types.

The data arranged in Table IV enable us to compare the accuracy of our color-measures with the Potsdam estimates. In this table the stars are arranged in order of the Potsdam colors. For convenience in taking averages we have added to the Potsdam notation in the third

than 2.3 before minimum is reached. The well-known contrasted colors of some wide double stars are also being investigated.

The provisional results of this investigation can be summarized as follows:

1. The photographic method furnishes a practically simultaneous determination of visual and photographic magnitudes, free from most of the uncertainties of visual methods.

2. The system used can be definitely stated by its spectral intensity curves, and exactly reproduced by any observer.

3. The color results are stated in magnitude differences, which are directly useful in photometric work and absolutely necessary in co-ordinating visual and photographic photometry.

4. As definite color-intensities correspond in general to definite spectral types, this furnishes a method of determining the spectrum of stars too faint for the ordinary spectroscope. One hour's exposure with eighteen inches on the reflector will give measurable colors of stars to the fourteenth magnitude.

Yerkes Observatory
January 1908

THE COLOR-SENSIBILITY OF SELENIUM CELLS

By JOEL STEBBINS

During the summer of 1907 a determination of the moon's light with selenium cells was made at this observatory by Mr. F. C. Brown and the writer.[1] It was found that the moon's candle-power was dependent upon the cell used, the values for the full moon ranging from 0.07 to 0.37 candle-meters. It was suggested that this discordance could easily be explained if the color-sensibility curves of the selenium cells were different, and this has since been found to be the case. The present paper gives a determination of the color-curves of the four cells which were used in the work on moonlight.

The curves are based upon the normal solar spectrum produced by a small grating spectroscope attached to the 12-inch refractor. The center of the sun's image was kept on the slit of the spectroscope, and the conditions were the same for all cells, except for the different degrees of atmospheric absorption which were beyond the control of the observers. The spectroscope is a modest affair, being next to the smallest size regularly manufactured by Brashear. The ruled surface of the plane grating is 19×25 mm, and the objectives of the collimator and view telescope are each of 19 mm aperture and 285 mm focal length. The cell to be tested was placed in the focus of the view telescope, and in front of the cell was a metal shutter with a slit about 1.5 mm wide. This slit extended across the spectrum, and its width corresponded to about 80 Ångström units in the first order, a sufficient stretch of spectrum to obscure the effect of the spectral lines. A number of elements of the cell were illuminated, but the area of the slit, 1.5×8 mm, was less than one hundredth of the entire sensitive surface of the cell, which was of dimensions 50×26 mm or larger. The necessary precaution was taken to insert additional diaphragms in the view telescope to cut off stray light.

The manipulation was similar to that of our work on the moon. The cell was connected as one arm of a Wheatstone bridge as before, and 13 dry batteries gave an E. M. F. of 15.5 volts. An exposure

[1] *Astrophysical Journal*, 26, 326, 1907.

time of 5 seconds gave convenient galvanometer deflections when the spectroscope slit was opened so that the intensity in the spectrum was what would be convenient for visual observations. The exposures were made every half-minute, and it was found that the cells would recover sufficiently in the interval of 25 seconds. After several

TABLE I

COLOR-SENSIBILITY OF GILTAY CELL NO. 94

November 23, 1907, 5-second exposures every half-minute from $0^h\,40^m.5$ to $1^h\,23^m.5$. Temperature, 15° C.; Resistance of cell, 850,000 ohms; 15.5 volts in circuit.

Circle	Wave-Length	Deflections			Sensibility in Terms of λ 6760
		Forward	Backward	Mean	
		mm	mm	mm	
16′ 0′	8980	14.4	13.6	13.8	0.245
16 0	8980	14.2	12.9		
16 30	8700	12.3	11.5	11.9	.211
17 0	8420	11.7	11.5	11.6	.206
17 30	8140	12.3	11.5	11.9	.211
18 0	7870	9.8	9.7	9.8	.174
18 20	7680	10.8	10.1	10.4	.184
18 40	7500	22.1	20.9	21.5	.381
19 0	7310	41.6	40.4	41.0	.727
19 10	7220	53.7	50.3	52.0	.922
19 20	7130	67.5	64.2	65.8	1.167
19 30	7030	79.7	72.0	75.8	1.344
19 40	6940	77.7	73.4	75.6	1.340
19 50	6850	65.7	60.4	63.0	1.117
20 0	6760	58.5	54.4	56.4	1.000
20 10	6660	47.5	45.1	46.3	0.821
20 20	6570	39.5	38.1	38.8	.688
20 30	6480	39.5	33.6	36.6	.649
20 40	6390	40.1	36.7	38.4	.681
20 50	6290	41.4	38.3	39.8	.706
21 0	6200	43.8	39.6	41.7	.739
21 10	6110	49.0	42.3	45.6	.808
21 20	6020	46.4	43.6	45.0	.798
21 30	5920	46.1	44.2	45.2	.801
21 40	5830	45.0	42.9	44.0	.780
21 50	5740	43.7	45.8	44.8	.794
22 0	5650	43.2	41.4	42.3	.750
22 10	5550	40.6	39.1	39.8	.706
22 20	5460	36.5	38.1	37.3	.661
22 40	5280	37.5	34.9	36.2	.642
23 0	5090	33.5	31.0	32.2	.571
23 30	4810	25.3	25.8	25.6	.454
24 0	4540	21.6	21.5	21.6	.383
24 30	4260	15.0	15.8	15.4	.273
25 0	3980	10.2	12.2	11.2	.199
26 0	3430	2.8	4.0	3.4	.060
27 0	2870	2.9	6.5	4.7	.083
28 0	2320	2.3	3.1	2.8	.050
28 0	2320	2.7	3.2		

trials to determine the approximate curve for each cell, a series of exposures was taken, beginning at the infra-red, and running through to the violet, then repeating in the reverse order. In Table I are the

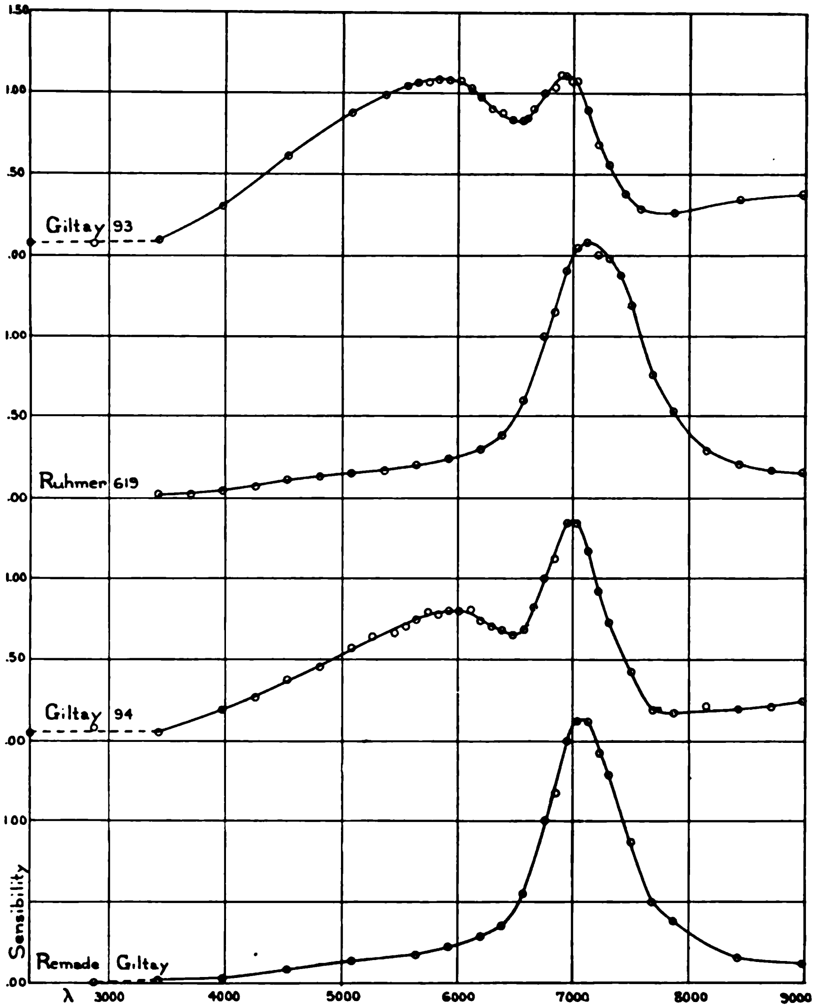


FIG. 1.—Curves of Color-Sensibility of Selenium Cells. λ

details of a determination for Giltay Cell No. 94. The wave-length corresponding to each circle reading was carefully determined and is correct within 20 Ångström units. The first and last deflections were

obtained at the first circle reading, 16° 0′. The sensibility in the last column is assumed to be proportional to the galvanometer deflection, and for convenience the sensibilities of each cell were referred to the value at λ 6760. The systematically smaller deflections obtained in the "Backward" column were due to the lower altitude of the sun, which had passed the meridian.

The results for the four cells are shown graphically in Fig. 1, where each small circle represents the mean of two deflections. When it is remembered that these are photometric measures in different parts of the spectrum, it will be seen that the general agreement of the observations with a smooth curve is exceptionally good. In fact, the probable error of a single deflection is often only 1 per cent. or less.

A glance at the curves shows that the candle-power should undoubtedly depend upon the cell used. The Giltay cells have two maxima, while the Ruhmer cell and the one remade here have but one maximum. Although the two Giltay cells have similar curves, they are not duplicates, and likewise the Ruhmer and remade cells do not have curves which are exactly alike. The methods of manufacture by Giltay and by Ruhmer are not known to the writer, and are presumably trade secrets. The remade cell was heated to the melting-point of selenium, 217° C., and was then annealed between 100° and 200° C. For completeness the color-sensibility curves should be determined for both moonlight and candle-light, but there are difficulties in the way of measuring spectral intensities of the moon and candle under the same instrumental conditions.

There is a certain amount of diffuse light reflected from the grating, which it is impossible to eliminate, and under the conditions of the experiments, it is believed that light of wave-length less than about λ 3400 had no effect upon the cells. This diffuse light probably affects all readings, and it might be allowed for by raising the line of zero sensibility for each cell. The results in the infra-red are also complicated by the effect of the second-order spectrum, which in some cases seems to begin near λ 8000.

It is certain that these curves are dependent upon the altitude of the sun, and the amount of atmospheric absorption. In fact, it will probably be possible to measure the selective absorption of the atmosphere with one of these cells, but it is necessary to wait till near the

time of the summer solstice. In Table II are given the conditions of the observations with each cell, also the positions of the observed maxima in the sensibility curves.

TABLE II

MAXIMUM SENSIBILITY OF SELENIUM CELLS

Cell	Astronomical Date, 1907	Central Standard Time	Sun's Altitude	Maximum	Second Maximum
Giltay 93...........	Nov. 16	0^h 18^m	30°	λ 6940	λ 5860
Ruhmer 619........	Nov. 23	21 53	25	7140	....
Giltay 94...........	Nov. 23	1 02	27	7000	6000
Remade Giltay......	Nov. 22	23 22	30	7080	....

From the above results we may conclude that selenium cells differ from each other in regard to color-sensibility much as do various brands of photographic plates, but there is not sufficient data at hand to determine how the color-sensibility curves depend upon the process of manufacture of the cells.

In conclusion, I beg to acknowledge my indebtedness to Dr. F. W. Reed and Mr. B. O. Brown, without whose assistance the observations could not have been taken; also to Professor A. P. Carman, who placed the facilities of the Department of Physics at my disposal.

UNIVERSITY OF ILLINOIS OBSERVATORY
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THE LIGHT-CURVE OF δ *CEPHEI*

By JOEL STEBBINS

The well-known variable star, δ *Cephei*, has been studied by many observers. Argelander determined the form of the light-curve, and found a secondary maximum or pause in the decline of light. This peculiarity has been verified by other observers, but many of the published light-curves disagree as to the time of the secondary maximum or as to its actual existence. Between June 1906 and September 1907, the writer has taken a long series of measures of δ *Cephei* with a polarizing photometer attached to the 12-inch refractor. The photometer is one of the first forms devised by Professor E. C. Pickering, and is fully described by him in *Annals H. C. O.*, **11**, where it is designated as Photometer H. As used by the writer the instrument has the improvement, which was introduced at Harvard, of a second prism in the focal plane, which renders the emergent beams coincident. Attached to the 12-inch telescope, the use of the instrument is limited to a comparison of stars not more that 1′ apart, but δ *Cephei* has a sixth-magnitude companion at 41″ distance, which has served as comparison star in all of the measures. The full aperture of the 12-inch objective was used, and experience has shown that bright stars are as easily measured as faint ones. The range of the variable is approximately from 3.6 to 4.3 magnitudes.

The method of observation was to take 16 settings with the right eye, then change to the left eye for 16 more, thus alternating until 6 sets or 96 settings had been secured. The result from 96 settings will be called an observation, and in 15 months there were obtained 74 observations or a total of 7104 settings. Usually the readings were recorded by an assistant, and the time required to make an observation was from 40 to 50 minutes. All possible precautions were taken to avoid systematic errors. The effect of position angle was eliminated by rotating the photometer, 8 settings of each set were taken with variable above, and 8 with variable below the comparison star. The observer's mind was closed as to the phase of the light-variation, and

the reductions were not made for at least a month after the observations. On two occasions two observations were taken on a night, but ordinarily 96 settings were deemed sufficient. When it happened that the measures were interrupted by clouds, and could not be resumed, the settings of the night were rejected, for it was determined to retain nothing but complete observations and to give equal weight to all.

The seeing was recorded on a scale of 5, although with the magnifying power of only 100 which was employed, 4 is apparently perfect. There was reason to anticipate that the presence of moonlight would affect the measures, especially since the variable is redder than the comparison star. Accordingly the amount of illumination was recorded on a numerical scale, 0 representing a dark field, 1 that the moonlight effect was just perceptible, and 5 the brightness of the field near the full moon. For this star the estimate of moonlight was never higher than 3.

In Table I are the results of each night. The phase is counted from an arbitrary date, 1906 June 30.25 G. M. T., and the adopted period is that given by Meyermann,[1] $5^{d}.366404$. The difference of magnitude in the fifth column is from the mean of 96 settings, and represents the amount that the variable was brighter than the comparison star. The residuals in column six are in the sense Observed minus Curve. The last two columns contain the estimates of seeing and moonlight.

Any grouping of observations is more or less arbitrary, and in this case this procedure was mechanical. The results were arranged in sequence according to phase, and each observation was combined with the one preceding and following. The 74 overlapping means thus found form the basis of the light-curve. However, it is possible for anyone else to use the individual observations in Table I, according to his own judgment.

From the residuals furnished by the 6 sets of each night is derived a probable error of one observation, of ± 0.010 magnitude. This is a measure of the accordance of results in a single night, but a much better test is given by the residuals in Table I, from which is derived a probable error of ± 0.014 magnitude for one observation. The

[1] *Astronomische Nachrichten*, 167, 1, 1904.

TABLE I

Photometric Measures of δ *Cephei*

No.	Date		G. M. T.	Phase	Diff. of Mag.	O.—C.	Seeing	Moon
	1906							
1......	June	30	15^h55^m	$0^d.413$	2.34	+.01	2	1
2......	July	1	15 33	1.398	2.22	+.04	2	2
3......	July	3	17 14	3.469	2.84	.00	2	2
4......	July	8	15 54	3.046	2.93	.00	2	1
5......	July	11	15 05	0.645	2.30	+.03	2	1
6......	July	14	16 44	3.714	2.78	+.03	2	0
7......	July	16	15 35	0.300	2.35	.00	2	0
8......	July	17	16 53	1.354	2.17	−.01	3	0
9......	July	18	16 54	2.355	2.49	+.02	2	0
10......	July	21	17 00	5.359	2.36	.00	2	0
11......	July	23	15 05	1.912	2.16	−.04	2	0
12......	July	24	16 34	2.974	2.92	.00	3	0
13......	July	26	14 52	4.903	2.47	−.02	2	1
14......	July	27	15 54	0.580	2.26	−.03	1	1
15......	July	29	14 59	2.542	2.62	.00	2	2
16......	July	30	16 15	3.595	2.81	+.02	3	2
17......	August	1	15 30	0.198	2.32	−.02	3	2
18......	August	2	15 08	1.183	2.18	−.02	2	3
19......	August	4	14 52	3.171	2.93	+.01	2	2
20......	August	9	16 52	2.888	2.92	+.01	2	0
21......	August	10	17 39	3.920	2.68	.00	3	1
22......	August	11	16 09	4.858	2.50	+.03	3	0
23......	August	12	14 40	0.430	2.32	.00	2	0
24......	August	16	15 57	4.484	2.58	.00	1	0
25......	August	20	14 56	3.074	2.90	−.03	2	0
26......	August	21	14 51	4.071	2.66	+.01	2	0
27......	August	22	15 07	5.082	2.42	.00	2	0
28......	August	23	14 57	0.709	2.23	−.03	3	0
29......	August	24	15 00	1.711	2.16	−.01	3	1
30......	August	25	14 39	2.696	2.78	.00	3	1
31......	August	27	14 09	4.676	2.56	+.01	2	2
32......	August	28	14 44	0.334	2.35	.00	3	2
33......	August	29	14 36	1.328	2.20	+.02	2	2
34......	August	30	14 36	2.328	2.44	−.04	2	2
35......	September	16	14 16	3.214	2.92	.00	2	0
36......	September	17	14 11	4.211	2.64	+.01	3	0
37......	September	19	14 15	0.848	2.22	−.01	3	0
38......	September	20	14 45	1.869	2.18	−.01	2	0
39......	September	22	13 45	3.827	2.69	−.02	3	1
40......	September	23	14 09	4.844	2.52	+.02	3	1
41......	September	24	13 49	0.464	2.34	+.02	3	1
42......	October	4	13 06	5.067	2.41	−.01	3	0
43......	October	7	13 18	2.709	2.80	.00	3	0
44......	October	21	12 36	0.581	2.28	−.01	3	1
45......	November	4	16 03	3.992	2.65	−.02	3	3
46......	November	9	15 57	3.621	2.76	−.02	2	0
47......	November	15	15 38	4.241	2.59	−.04	2	0
48......	November	23	15 40	1.510	2.17	.00	2	2
49......	November	24	15 01	2.483	2.59	+.04	3	2
50......	December	1	14 50	4.109	2.63	−.02	3	3
	1907							
51......	January	5	15 02	1.552	2.11	−.06	0	0
52......	February	14	14 11	3.952	2.66	−.02	2	0

TABLE I—*Continued*

No.	Date	G. M. T.	Phase	Diff. of Mag.	O.—C.	Seeing	Moon
53......	February 19	$13^h 44^m$	$3^d 567$	2.76	−.05	1	1
54......	February 25	13 43	4.200	2.64	+.01	1	2
55......	June 16	17 35	2.667	2.76	+.01	2	0
56......	July 5	15 39	0.120	2.36	+.01	1	0
57......	July 7	15 29	2.113	2.34	+.02	2	0
58......	July 7	16 58	2.175	2.36	+.01	3	0
59......	July 12	15 50	1.762	2.20	+.03	3	0
60......	July 12	17 07	1.815	2.20	+.02	3	0
61......	July 26	15 25	5.011	2.47	+.02	2	1
62......	August 5	15 52	4.297	2.67	+.06	3	0
63......	August 7	15 20	0.909	2.26	+.05	3	0
64......	August 9	15 13	2.904	2.92	+.02	2	0
65......	August 10	14 46	3.885	2.74	+.04	3	0
66......	August 12	15 08	0.534	2.30	.00	2	0
67......	August 18	14 46	1.152	2.19	−.01	2	2
68......	August 23	14 35	0.778	2.24	−.01	3	3
69......	August 24	14 25	1.771	2.17	.00	2	2
70......	August 25	14 24	2.770	2.83	.00	4	1
71......	August 29	14 17	1.399	2.18	−.01	3	0
72......	August 30	14 09	2.394	2.48	−.01	3	0
73......	September 10	14 46	2.686	2.76	.00	2	0
74......	September 12	14 20	4.668	2.52	−.03	3	0

latter value shows that the systematic errors on a given night are small, and justifies the large number of readings.

If we assume that the observed difference of magnitude varies linearly with the estimate of seeing or of moonlight, from the first observation we may set up the equation

$$2s+1m=+.01$$

where s represents the change of the difference of magnitude with a unit variation in the scale of seeing, and m a similar coefficient for the moonlight effect. A least-square solution of the 74 equations gives

$$s=+0.0024,$$
$$m=-0.0030.$$

These quantities are negligible, and we may conclude that there is no evidence of any effect due to variation in the steadiness of the images or illumination of the field. It seems therefore that the observations cannot be further improved.

In Fig. 1 the circles represent the overlapping means, which are sufficiently numerous to indicate the variations in brightness without the curve. It will be seen that there are no large irregularities, but

there is evidence of secondary fluctuations with maxima at about $4^{d}.6$, and $0^{d}.4$. The first of these, which probably corresponds to the secondary maximum of Argelander, is in excellent agreement with the photographic results of Wirtz[1]. Both Wirtz and Meyermann[2] have also found evidence of the irregularity at $0^{d}.4$. The discordance of the points near minimum is probably due to the observation No. 51, which was taken under the poorest conditions, the seeing being esti-

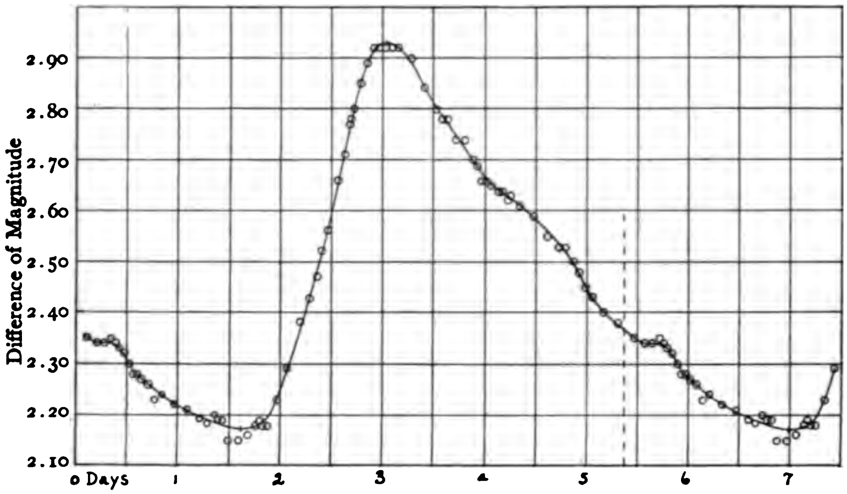

FIG. 1.—Light-Curve of *δ Cephei*.

mated at 0. The measures on that night were satisfactory at the time, and the writer has adhered to the rule of rejecting no observations after they were once taken. The curve has been drawn according to the writer's judgment, but on account of the large number of observations it would not be possible to change the form of the curve to any extent. It should be mentioned that all of the observations depend upon one comparison star, but there is no evidence that all of the changes are not due to the variable.

The times of maximum and minimum, and the amplitude of variation, as derived from the curve, are as follows:

[1] *Astronomische Nachrichten*, 154, 334, 1901.

[2] *Ibid.*, 175, 1, 1907.

Maximum	2.93 mag.	1906 July 3.29 = J. D. 2417395.29 (Greenwich)
Minimum	2.17	1906 July 1.87 = J. D. 2417393.87
Amplitude	0.76 mag., Max. − Min.	$= 1^{d}.42$.

Meyermann gives for the maximum

1840 September 26.3588 + $5^{d}.366404$ E. (Bonn),

and from the writer's observations is derived a correction to the ephemeris of $-0^{d}.07$. This is probably within the error of the determination of maxima from different curves.

In 1894 Belopolsky[1] found δ *Cephei* to be a spectroscopic binary, and although the variations in radial velocity indicate an orbital motion which is synchronous with the change of light, the star is not an eclipsing system. More recently a number of variables of this type have been studied spectrographically at the Lick Observatory, and the results as summarized by Albrecht[2] show that these stars are brightest at the time of most rapid approach. In the case of *W Sagittarii* and *Y Ophiuchi* there is a close relation between the secondary fluctuations in light and radial velocity. Although δ *Cephei* is the brightest star of this class and can be reached with a three-prism spectrograph, no determination of the velocity-curve has been made since the work by Belopolsky. In view of the many improvements in spectrographs in the last ten years, it would seem that a series of observations with a modern instrument should yield interesting and valuable results.

UNIVERSITY OF ILLINOIS OBSERVATORY
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[1] *Astronomische Nachrichten*, **136**, 281, 1894.

[2] *Astrophysical Journal*, **25**, 330, 1907.

THE LUMINOUS PARTICLE A STRONG MAGNET, AND THE CONSEQUENT PRESSURE-SHIFT OF SPECTRAL LINES

By W. J. HUMPHREYS

In the *Philosophical Magazine* for November 1907, ((6) **14**, 557) Professor O. W. Richardson discusses in an excellent manner the pressure-shift of spectral lines. In outlining his method he says:

> Briefly stated, the theory to be developed attributes the displacement of spectral lines produced by pressure to the effect of sympathetic vibrations occurring in the surrounding atoms. The fact that an atom A is emitting light shows that it is surrounded by an alternating field of electric force. This alternating electric field will produce forced vibrations of equal period and, under certain conditions, of like phase in neighboring atoms. The electric field due to the forced vibrations will react on the emitting electron in the atom A, and, as will be shown, in such a way as to increase the period of the latter. It will be necessary, then, to calculate the reaction at A due to the forced vibrations set up in an atom at B by a given vibration at A, to sum this up for all the atoms B which occur, and to find the effect of the resultant reaction on the period of A.

After detailed calculation the following equation is obtained:

$$\frac{\delta\lambda}{\lambda_0}=\frac{\epsilon^2\lambda^2{}_0(\mu^2-1)}{6\pi^2 mc^2a^3},$$

in which $\delta\lambda$ is the change in wave-length λ_0, ϵ the charge of the electron, m the mass of the electron, c the velocity of light, μ the refractive index of the medium for light of the given wave-length λ_0, and a "the radius of the sphere within which it is impossible for the center of an atom of class B to lie." "It is evident that a will be of the order of magnitude of the radius of the atom A and have the sum of the radii of A and B as an upper limit."

This equation requires the change in wave-length to be positive, or toward the red, to increase directly as the density or pressure of the surrounding gas is raised, and finally to be directly proportional to the third power of the wave-length examined. The first two requirements agree with the facts of experiment, but the third does not. The pressure-shifts of different lines of even the same element vary greatly, but while there is an undoubted increase in the average

shift with increase in wave-length, it is roughly proportional to the first and not to the third power of this value. Besides, the shifts calculated from Professor Richardson's equation are from five to twenty-five times greater than those given by experiment. Presumably, then, the assumed structure is not very nearly that of the actual atom. However, some modification of it may bring the calculated and the observed results much closer together. At any rate this is the place where a great deal is needed both of experiment and of theory, and every careful experiment and every theory minutely worked up must bring us nearer to that important goal—the structure and the mechanics of the atom.

In another part of his paper Professor Richardson considers the effect of the magnetic interaction of luminous atoms, based on the assumption "that the magnetic field of any atom is not greater than that which corresponds to saturated iron," and concludes that this action is entirely too small to produce the observed shifts.

But, since the magnetic permeability and the point of saturation of a piece of iron or other substance depends upon its physical condition, and upon the extent to which it is alloyed or combined with other elements, it does not seem likely that the magnetic intensity of any material in bulk is the same as that of its constituent atoms. However this may be, it is always safer to rely upon direct experimental evidence whenever obtainable, and this I believe we have for the luminous atom, as will be explained below.

Experiment shows that one magnetic field can be acted on by another, and no other method of acting on it has been discovered; that a magnetic field always accompanies an electric current, and no other source of magnetism is definitely known; and that a moving electric charge is an electric current. For these reasons it appears certain that the luminous particle, which is influenced by a magnetic field, possesses a magnetic field of its own, due to moving electric charges; negative, as experiment assures us, in their nature. Besides, we know that spectral lines, when produced in a magnetic field, are split up into parts, one portion of the line having a greater and another a less wave-length than that of the undisturbed line. And this means that the electrons are moving in such a manner that their periods may be increased or decreased owing to the orientation of the atom to the

disturbing field, a condition fully met by assigning to them circular or elliptical orbits.

Therefore assume a structure consisting of one or more circular rings of electrons in orbital motion, all rings coplanar and all revolving in the same sense around a common axis. The electrons in any given ring may be temporarily bunched to some extent or otherwise disturbed, but their normal condition will be one of equal angular distribution, and of equal angular velocity, as viewed from a point on the axis. And all these rings will be inductively bound together, so that to change, by means of an external magnetic field, the angular velocity of any one is to change in the same sense, but not necessarily to the same extent, the angular velocity of every other.

For the sake of simplicity consider a single such ring of electrons. It has been shown by Langevin[1] that only the angular velocity, and not the orbital radius, of such a ring will vary when it is placed in a field of changing magnetic strength. Therefore the value of its self-induction is a constant, and consequently any current induced in it is given by the equation

$$E=L\frac{di}{dt}+Ri,$$

where E is the induced electromotive force, L the self-induction of the circuit, $\frac{di}{dt}$ the rate of change in the current, R the ohmic resistance of the circuit, and i the strength of the current. But in this case the circuit consists of only a single turn, and therefore $E=\frac{dN}{dt}$, or the electromotive force is directly proportional to the rate of change of the number of lines of magnetic force threading the ring. Besides, as the electrons presumably meet with no resistance in their orbits, $R=O$, and hence $di=\frac{dN}{L}$; that is, the induced current is always proportional to the total change in the magnetic flux through the circuit, and of the same sign; and further, every induced current persists without change so long as the new flux through the circuit is not allowed to vary.

[1] *Journal de physique* (4), 4, 678–692, October 1905.

Such a ring of electrons will produce ether vibrations of the wave-length λ determined by the relation

$$\frac{V}{\lambda}=\frac{n\omega}{2\pi}=KS\ , \tag{1}$$

where V is the velocity of light, n a numerical coefficient, ω the angular velocity of the electrons, S the average strength of the magnetic field inclosed by the orbit and due to the moving electrons, and K a constant whose value is determined by the orbit, the number, and the charge of the electrons. But, whether the wave-frequency of the spectral lines is the same as the frequency of the orbital revolutions of the electrons, or only some multiple or submultiple of it, is immaterial to the subsequent argument, as any change in this particular would simply change the value of S. It is only necessary that the wave-frequency be directly dependent upon this orbital revolution, so that any changes in the period of this revolution will produce proportional changes in the wave-frequencies of the spectral lines.

Since V is either constant or approximately so we get from equation (1)

$$-\frac{Vd\lambda}{\lambda^2}=KdS\ . \tag{2}$$

Therefore, from (1) and (2),

$$-\frac{d\lambda}{\lambda}=\frac{dS}{S}\ . \tag{3}$$

But dS can be obtained by bringing a magnetic field of strength H to bear on the particle, in which case (3) becomes

$$-\frac{d\lambda}{\lambda}=\frac{H}{S}\ . \tag{4}$$

By substituting H for dS in (2) we get

$$\frac{d\lambda}{H\lambda^2}=C\text{, a constant.} \tag{5}$$

But this is the well-known Zeeman law, and therefore it appears quite likely that the assumed ideal particle is closely akin in structure to the actual luminous particle. In general such particles, as the distance between them changes, will be mutually affected inductively. When their north poles or their south poles face each other the wave-frequency will be increased and the wave-length decreased as they

mutually approach, since in this case the induction will be such as to increase the current, that is, to increase the orbital speed of the electrons; but as they recede, like poles still facing each other as before, the induction will be such as to increase the wave-length. When, however, the north pole of one faces the south pole of another, the wave-length will increase as they approach and decrease as they recede. In all cases, then, the mutual approach of luminous atoms means a shifting of their spectral lines to the red or to the violet, as the case may be, while their recession is accompanied by a corresponding restoration of the lines to their undisturbed positions—their positions when the luminous gas is very rare, and the lines narrowest and best defined. Presumably, therefore, the widths of spectral lines are due in large measure to the mutual induction of their luminous atoms, the extent of which action must necessarily be independent of the absolute strengths of their magnetic fields. That is, a weak field will affect another equally weak field by the same proportion of itself that two strong ones similarly situated will affect each other. But if their fields are very weak only a nearly symmetrical broadening of the spectral lines will be produced, since, in this case, the particles in their movements under the influence of temperature will approach almost equally close together whether they face so as mutually to attract or to repel; that is, so as to increase or to decrease the orbital periods of their electrons through induction. If, however, their magnetic fields are strong the effect will be a broadening together with a shift of the maximum intensity to the red, since when attracting, and thus mutually inducing counter-currents, they will get distinctly closer together—each into the stronger portion of the other's magnetic field where the induction is correspondingly greater—than they will when the reverse is the case.

It remains then to find the strength of their fields, and this is easily done by the use of equation (4), in which all the terms except S are directly measurable. By substituting known values for these terms it is found that $S = 45 \times 10^7$, approximately, which is some thousands of times that of the most powerful electromagnet; and therefore an unsymmetrical broadening or shift of the order measured is to be expected.

Particles with such strong fields, darting about under the influence of

temperature, would face each other, and whirl each other about, in a manner analogous to that assumed by Ewing[1] for the molecules of hot iron, and to an extent well-nigh independent of the relatively feeble field of any electromagnet. An independence of this nature also seems to be demanded by the Zeeman effect, since the shifted portions, those increased in wave-length and those decreased, of any spectral line are of nearly, if not quite, equal intensity.

MOUNT WEATHER OBSERVATORY, VA.
December 1907

[1] *Magnetic Induction in Iron and Other Metals*, p. 334.

NOTE ON THE DIFFERENCE BETWEEN ANODE AND CATHODE ARC-SPECTRA

By W. J. HUMPHREYS

It was noticed long ago, by Lockyer among others, that the spectrum produced by an electric arc depends in part upon the portion of the arc examined. This difference, which may be very pronounced when the regions near the opposite poles are contrasted, has been studied by Thomas,[1] Baldwin,[2] Foley,[3] and Beckmann.[4]

While their results differ in minor details, due no doubt to differences in the poles used and in the methods of observation, they all agree in the essential point: that is, that, other things being equal, the metallic lines are most pronounced near the negative pole and least conspicuous near the positive pole. Further, they all agree in attributing the difference in the spectra of the two poles to unequal concentration of the material producing the lines, but they do not agree as to the cause of this unequal concentration. The first three attribute it chiefly to an electrolytic action in the arc, causing the electropositive particles to accumulate on and around the negative pole. Foley decides positively for electrolysis, but claims that convection currents due to heated gases may even mask the true electrolytic process.

On the other hand, Beckmann declares against electrolysis. He claims that if there is electrolysis in the arc, then, when the poles contain both potassium and manganese, the potassium must appear at the negative pole and the manganese at the positive. But he says that he found no such separation, and that therefore electrolysis is absent; that only convection, diffusion, and distillation are involved, and that sometimes the one and sometimes the other, as circumstances are changed, must predominate.

[1] *Comptes Rendus*, 119, 728, 1894.

[2] *Physical Review*, 3, 370 and 448, 1896.

[3] *Ibid.*, 5, 129, 1897.

[4] *Zeitschrift für wissenschaftliche Photographie*, 4, 335, 1906.

I had often noticed differences in the intensity of the metallic lines from regions near the two poles, and a few months ago examined them more minutely. Carbon poles with only impurity traces of metals were used, with the view of making the contrast as distinct as possible. When either pole is heavily charged with one or more metals or their salts, the entire arc becomes filled with metallic vapor, probably as a result of distillation, sputtering, convection currents, etc., and contrast between the spectra of the two electrodes is not marked. When both poles are so filled there is practically no difference between their spectra. Under such circumstances it is quite likely that minute particles of the salt or metal fill the arc, and that each, being conducting, is on one side the terminus and on the other the origin of a small arc; that is, it carries with itself both a positive and a negative pole, so that the whole arc is made up of a great number of infinitesimal arcs that utterly prohibit a study of the contrast between the two poles. Probably, however, this condition is reduced to a minimum when carbon poles with mere traces of metals, or their salts, are used. At any rate, poles of this nature give very marked contrasts in their spectra.

My observations were made with a large Rowland concave grating, and the trouble from astigmatism was practically avoided by forming an image of a long arc on a screen standing against the slit, with two small but equal holes in it; one just within the image of the positive pole, the other just within the image of the negative. These two sources gave each its own spectrum, and by using the first order they were kept from overlapping. Everything was therefore the same for the two spectra except the sources of the light.

The poles contained traces of aluminium, calcium, chromium, iron, manganese, silicon, strontium, and titanium; all of which showed many times stronger near the negative pole than near the positive. On the other hand, the cyanogen bands and the solitary carbon line were more pronounced at the positive pole.

My observations therefore are in general accord with those of others, but I cannot agree with them as to the sufficiency of their explanations of the reason of this difference, which really seems to suggest what is one, and it may be the only, exciting cause of spectrum lines.

It is shown by J. J. Thomson in his *Conduction of Electricity through Gases* that presumably the arc consists mainly of negative corpuscles moving with great velocity from the negative to the positive pole, together with an approximately equal number of positive ions moving much more slowly in the opposite direction. The principal part of the current then is due to the negative corpuscles that leave the negative pole, ionize the gas of the arc mainly next the positive pole, and finally by their bombardment keep the positive pole itself hot. The positive ions, in a similar manner, heat the negative pole—the most important condition for the maintenance of the arc.

Of course convection, diffusion, and distillation must enter as factors in the distribution of material in the arc, but the positive "rest-atoms," in whatever part of the arc they appear, drift under the voltage applied toward the negative pole, in the neighborhood of which they are met more frequently than elsewhere by the negative corpuscles, and that, too, in their first and violent rush from the cathode. The negative corpuscles of course, so long as they are free, move toward the anode, but while some may go on for a time undisturbed, others will be slowed up or even unite with positive charges, so that the combined energy of the stream of corpuscles grows less and less as the positive pole is approached.

The location of the strongest part of the spectrum lines next the negative pole is thus assumed to be due to the presence there of the greatest number of negative corpuscles with velocities capable of producing spectrum disturbances in the positive "rest-atoms," and possibly, but by no means certainly, to an accumulation in the same place of the "rest-atoms," themselves. The mere process of ionization, if the structure of the arc is correctly assumed, cannot produce spectrum lines, since they are least conspicuous near the positive pole, where this phenomenon is most pronounced.

The fact that the negative part of the arc is more concentrated than the positive also tends to emphasize the difference between the anode and cathode spectra, especially when the slit of the spectrometer is parallel to the length of the arc, since in this case a larger proportion of the total light from the negative pole will get through the slit than of that from the positive. However, the same difference, though apparently less pronounced, persists when the light from

sections at right angles to the arc, but near the poles, is integrated with a concave grating.

It would appear then that one, and it may be the only, origin of spectrum lines is the shocks of "rest-atoms" by swiftly moving negative corpuscles.

My experiments were made in the physical laboratory of the University of Virginia, and I thank Professor Smith and President Alderman for their kindness in placing its facilities at my disposal.

MOUNT WEATHER OBSERVATORY
Bluemont, Va., December 1907

THE TOWER TELESCOPE OF THE MOUNT WILSON SOLAR OBSERVATORY[1]

By GEORGE E. HALE

In a previous paper[2] I have outlined some of the conditions to be met in designing a fixed telescope for solar research. The change of figure of the mirrors on exposure to the sun, and the disturbance of the definition caused by heated currents of air rising from the ground, are the principal difficulties encountered. Since exposure to sunlight ordinarily produces actual bending of the mirrors, the use of very thick disks is naturally suggested. Again, since currents of warm air rising from the earth rapidly become mixed with cooler air at higher levels, a point of observation even 50 or 60 feet above the ground offers very definite advantages. Accordingly, the design adopted and described in my paper consists of a coelostat with very thick mirrors, mounted at the summit of a skeleton steel tower about 65 feet in height. The second mirror used with the coelostat stands near the center of the tower and sends the beam vertically downward through a 12-inch (30.5 cm) visual objective, by Brashear, of 60 feet (18.29 m) focal length (Fig. 1). The image of the sun is thus formed by this objective at a point about 5 feet (1.5 m) above the level of the ground, within a small building standing at the base of the tower.

It will be seen that the arrangement described comprises the following points of advantage: (1) great thickness of mirrors, to reduce astigmatism and rapid change of focal length; (2) the use of an objective, instead of a concave mirror (as employed in the Snow telescope), giving the shortest possible path between the coelostat and the focal plane and greatly decreasing the change of focal length experienced with a concave mirror; (3) the use of a vertical beam of light, with less probability of disturbance across the wave-front than in the case of a horizontal beam. Moreover, this type of telescope is well adapted for use in connection with an underground laboratory, in which power-

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 23.

[2] *Contributions from the Solar Observatory*, No. 14; *Astrophysical Journal*, 25 68–74, 1907.

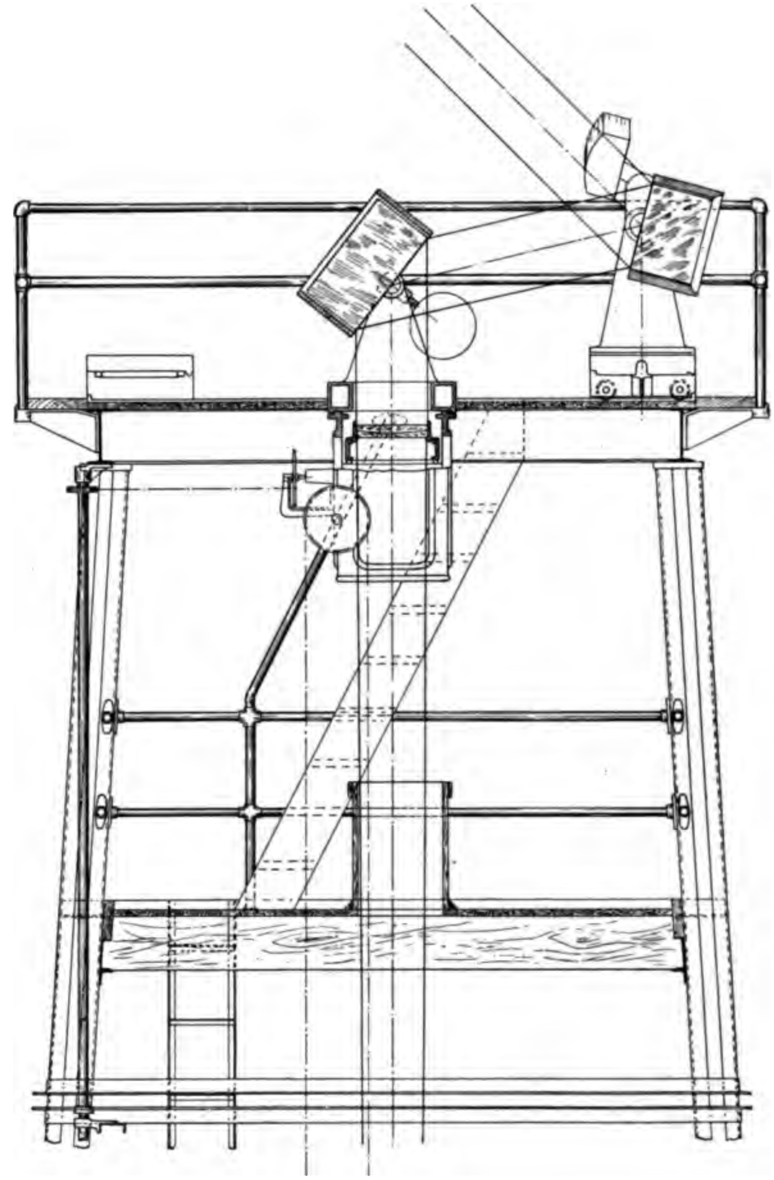


FIG. 1.—Section through upper end of Tower

ful spectrographs and other instruments requiring constancy of temperature and freedom from vibration can be mounted.

Soon after the publication of the paper cited, a special grant from the Carnegie Institution permitted the construction of the "tower" telescope to be undertaken. On account of the great pressure of work in our own instrument shop, it was not feasible to construct here the coelostat and the mounting for the second mirror and objective, or the Littrow spectrograph. Accordingly, the former were built by Brashear, and the spectrograph by Gaertner, from our working drawings. The steel tower, purchased from the Aermoter Company of Chicago, was set up on Mount Wilson last July. The coelostat mirror, 17 inches (43.2 cm) in diameter and 12 inches (30.5 cm) thick, and the elliptical mirror, also 12 inches thick, with major axis of 22½ inches (56.5 cm) and minor axis of 12¾ inches (32.4 cm), were both made in our optical shop under the direction of Mr. Ritchey. All of the other parts of the instrument, including the platform at the summit of the tower, the rails on which the coelostat carriage slides, the vertical shaft and driving mechanism for moving the 12-inch objective (when the instrument is used with a spectroheliograph), the house at the foot of the tower, supports for the spectrograph, etc., were built by our own workmen.

Plate XII is reproduced from a photograph of the tower telescope.[1] In the original design an outer tower, covered with canvas louvers, was provided to protect the inner one from the wind. However, on account of the importance of avoiding convection currents, which might result from heating of the outer tower, it was thought best to try the experiment of using the inner tower alone, without wind protection. This has proved so satisfactory that it is hardly likely the outer tower will be added. In a windy country a single tower would not be stable enough, but on Mount Wilson, where the average wind velocity during the best observing hours, especially in summer, is very low, the present arrangement seems likely to suffice. The use of a number of steel guy ropes is of course essential.

[1] This photograph was taken from a point northeast of the tower, and shows the Snow telescope house in the background The small shelter standing on the south side of the platform at the summit of the tower is placed over the coelostat when the telescope is not in use.

PLATE XII

The Tower Telescope
The Snow Telescope appears in the background

Fig. 1 shows, in general outline (from the north), the arrangement of the apparatus at the summit of the tower. The coelostat carriage stands on rails, which permit it to be moved north and south. As the best definition is obtained with the low morning or afternoon sun, the apparatus is designed to give the greatest efficiency at such times. When observing the morning sun, the coelostat stands on the west rails, its position in a north-and-south line being determined by the declination of the sun for the date in question. When it is to be used for afternoon observations, the coelostat is transferred, by means of a carriage rolling on east-and-west rails, to the rails east of the second mirror. The second mirror is then turned so as to face the coelostat mirror, and the beam sent vertically downward as before.

The object-glass, which stands just below the second mirror, is mounted in a support which can be moved vertically, for focusing, by a steel tape controlled by a hand-wheel near the focal plane (Plate XIII). It can also be moved in an east-and-west direction by means of a screw connected with a vertical shaft driven by an electric motor in the house at the foot of the tower.[1] The image of the sun can thus be made to move at a uniform rate across the collimator slit of a spectroheliograph, the same motor being employed to move the photographic plate, at the same rate, across the camera slit.

Plate XIII shows the slit-end of the 30-foot spectrograph, in the house at the base of the tower. The underground chamber in which the spectrograph stands is a circular well, 8½ feet (2.6 m) in diameter and 30 feet (9.1 m) deep. The walls are built of concrete and contain several layers of building paper, heavily coated with tar, to make them perfectly water-tight. Having once been thoroughly dried out, the walls have since shown no traces of moisture.

The spectrograph has proved to be an extremely satisfactory instrument. It is of the Littrow or auto-collimating type, and the construction is very simple. A slit, 2 inches (51 mm) long, is mounted at the end of a short tube at the center of the circular iron casting which forms the upper extremity of the instrument. This casting is connected with another iron casting at the bottom of the underground chamber by means of a skeleton steel tube (Fig. 2). The lower cast-

[1] The vertical shaft appears in the drawing and photograph, but many of the details of the connections are not shown.

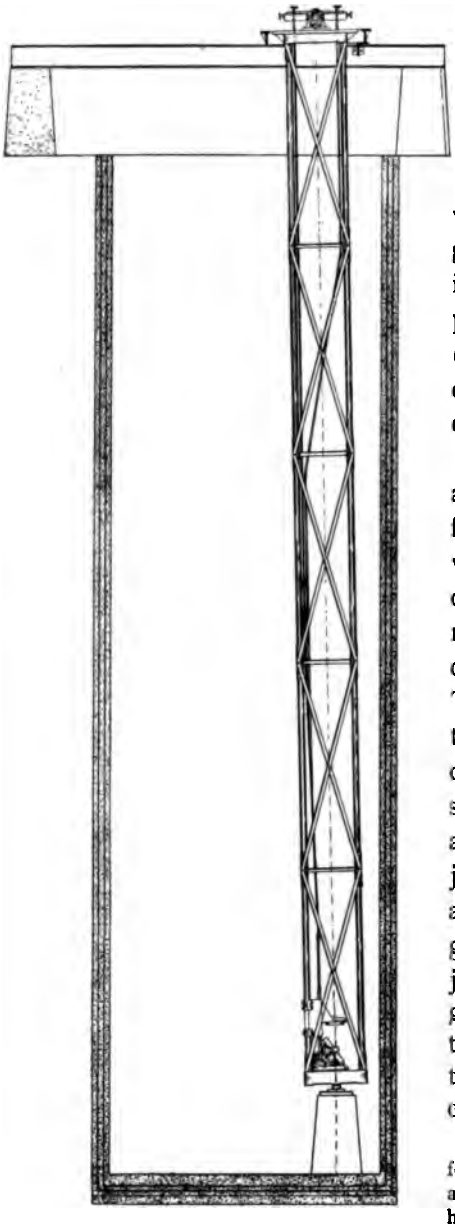


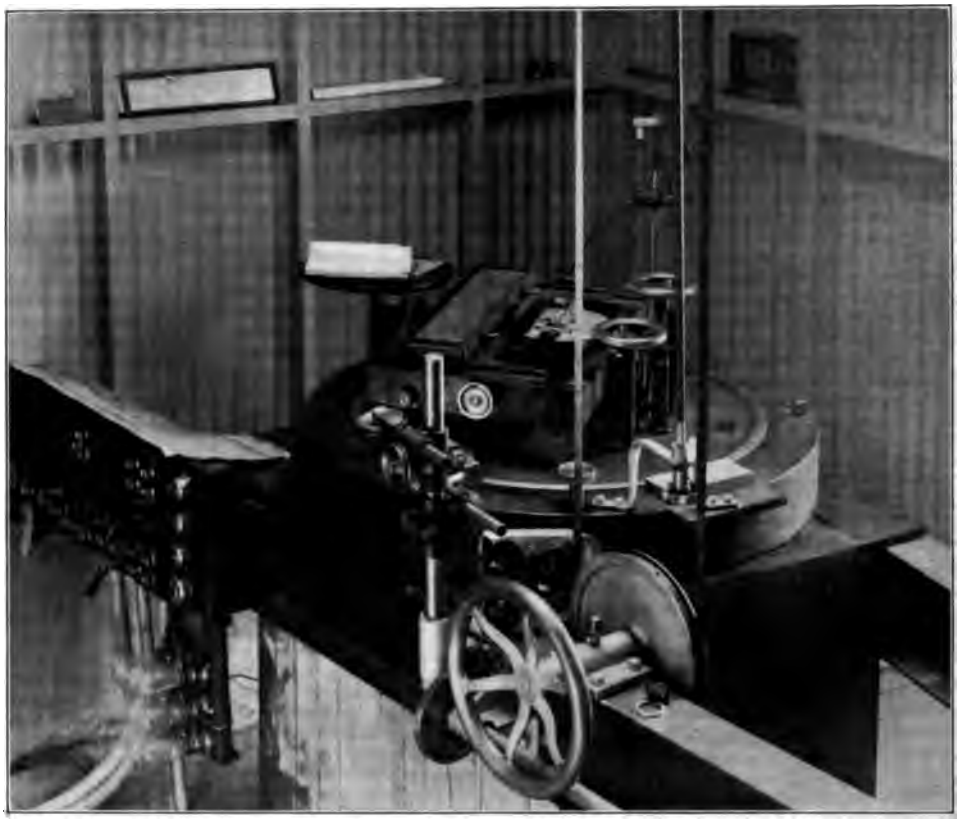
FIG. 2.—Section through underground chamber beneath Tower.

ing terminates in a hemispherical head, which rests on a cast-iron support mounted on a concrete pier. Thus the spectrograph can easily be rotated about a vertical axis,[1] by means of a gear-and-pinion attached to the iron ring which defines the position of the upper casting (Plate XIII). A large divided circle permits the position angle of the slit to be read.

Light from the solar image, after passing through the slit, falls on a 6-inch (15.2 cm) visual objective, by Brashear, of 30 feet (9.1 m) focal length, mounted near the lower end of the skeleton tube (Fig. 2). This lens can be moved vertically for focusing, by means of a rod terminating near the slit. The grating, mounted in a support just below the objective, can also be rotated from above by a similar rod. Scales giving the position of the objective and the angle of the grating can be read with a small telescope from the upper end of the instrument by the aid of electric illumination.

[1] This axis is actually inclined a few degrees from the vertical, to afford space for the 30-foot spectroheliograph, which will occupy a symmetrical position on the east side of the well.

PLATE XIII



SLIT-END OF THE THIRTY-FOOT LITTROW SPECTROGRAPH

The image of the spectrum is formed on a plate 17 inches (43 cm) long, carried in a plate-holder which can be moved parallel to itself, by rack-and-pinion, so as to permit a large number of narrow spectra to be photographed side by side. The width of the exposed portion of the plate is defined by two adjustable bars, standing a short distance in front of the plate, and independently movable by rack-and-pinion. The plate is shielded from reflected light by a bar placed across the collimating-camera objective. The plate-holder can be inclined so as to make an angle greater than 90° with the incident beam, but with the visual objective employed this is necessary only in the violet.

The spectrograph is furnished with several pieces of auxiliary apparatus, including a device for bringing to the slit light from opposite ends of a solar diameter (employed in spectrographic observations of the solar rotation); a similar device permitting spectra of the center and the limb of the sun (or some point lying between limb and center) to be photographed simultaneously; and a moving plate-holder, with two slits, which permits the spectrograph to be converted into a spectroheliograph.

The first tests of the tower telescope showed that rapid changes of focal length need not be feared. In the Snow telescope these changes are very different on different days, and frequently amount to several inches after the mirrors have been exposed ten minutes to the sun. Moreover, the focal length is increased by such exposure, which would naturally be the case if the heating caused the mirrors to become convex. A considerable part of the effect is doubtless to be attributed to the distortion of the concave mirror, but the change of figure of the two plane mirrors is also an important factor, as is demonstrated by the marked evidences of astigmatism presented by the solar image after continuous exposure of the mirrors. In the case of the tower telescope, when used in the early morning, there is no appreciable change of focal length after the mirrors have been exposed to the sun for about half an hour. Later it appears that the focal length is gradually decreasing, and by noon, after continuous use of the instrument, the change may amount to from four to six inches. In the afternoon the focal length increases, finally returning to the early morning value.

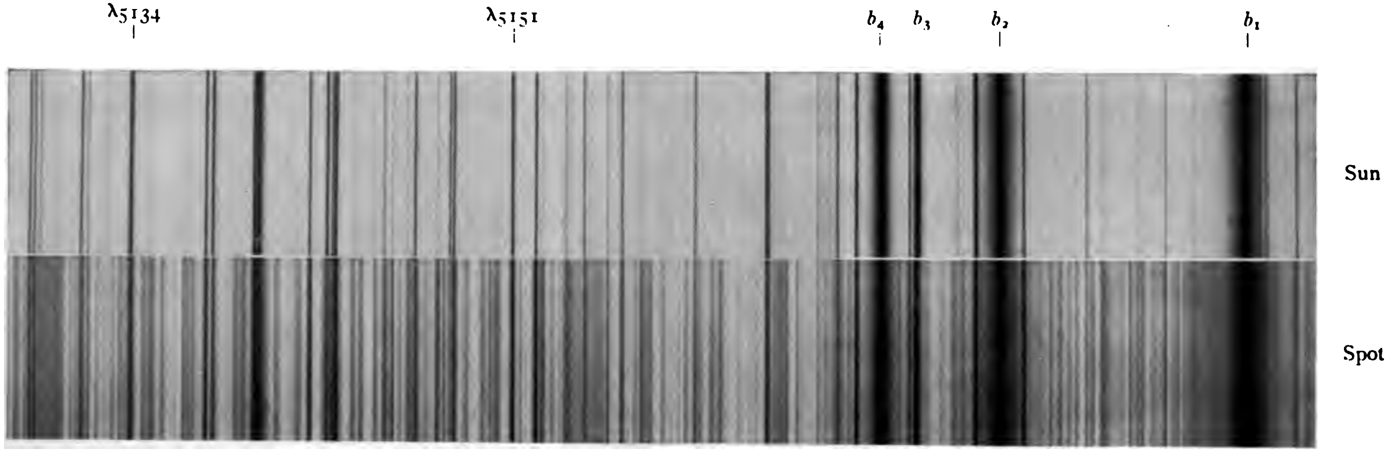
It is evident that the conditions here are very different from those encountered in the case of the Snow telescope. In fact, exposure to

sunlight seems to have very little influence on the figure of the mirrors, which continues to change in the manner above outlined even when both mirrors are shielded from the sun. The observed change of focal length must then be due to the change in temperature of the air. With such thick mirrors, the gradual heating of the air during the morning hours would result in expansion of the edges, causing the front and rear surfaces to become concave. This would produce astigmatism which, however, has not yet been noticed before eleven o'clock in the morning, and is not serious until a later hour. Thus the changes in the image are not of such a character as to give serious trouble, since the definition holds well during several hours and the change of focal length is slow enough to permit long exposures to be given. Hence the purpose for which the telescope was built has been accomplished. Nevertheless, the evidence goes to show that the mirrors are thicker than they should be, and for this reason their thickness will probably be reduced as soon as circumstances permit.

The second point to be considered is the quality of the image as affected by the condition of the air about the telescope. To test this, simultaneous observations have been made on several occasions with the Snow and the tower telescopes. In order to make the tests as fair as possible, the aperture of the Snow telescope was stopped down to 12 inches, and the mirrors were exposed to the sun for so short a time as to obviate any such effects of poor definition as would arise from their change of figure. In all cases it has been found that the tower telescope gives a more sharply defined image, the improvement in the "seeing" being from one to two points on a scale of ten. With the Snow telescope, all of the work requiring good definition must be done within a period of about an hour in the early morning or late afternoon. With the tower telescope, the definition is excellent during a much longer period. In fact, except for an interval near noon, this instrument can be kept in active use throughout the day for observations of an exacting nature.

The great focal length of the 30-foot spectrograph has also proved highly advantageous. The only grating available for work in the higher orders is a 4-inch (10.2 cm) Rowland, formerly employed at the Kenwood and Yerkes observatories, and used on Mount Wilson in all of our observations with the 18-foot (5.49 m) Littrow spectro-

PLATE XIV



REGION OF *b* LINES IN SPECTRUM OF SUN AND SPOT
The scale is that of Rowland's Map

graph. In my experience in photographing sun-spot spectra, which began at the Kenwood Observatory in 1891, I have used this grating in spectrographs of 42½ inches (1.08 m), 7 feet (2.13 m), 18 feet (5.49 m), and 30 feet (9.1 m) focal length. A decided gain has invariably resulted from each increase of focal length, even in the spectra of the third and fourth orders. The grating is not a perfect one, but its definition may be called good. In the 30-foot spectrograph of the tower telescope the ruled surface, being but 53×83 mm, of course receives only a small part of the light from the 6-inch objective, which is completely filled by the solar beam. In spite of the long exposures thus required, our recent photographs of sun-spot spectra, though taken under the unfavorable atmospheric conditions of November and December last, are decidedly superior to those obtained with the 18-foot spectrograph and the Snow telescope during the best observing period last summer, when much larger spots were available. The photographs reproduced in Plate XIV, on Rowland's scale, were widened with a pendulum apparatus which does not retain the full sharpness of the original negatives. A more perfect device, now under construction, will be used in making the enlargements required for our new map of the spot spectrum. This is to replace the preliminary map, a few copies of which were distributed last year to observers taking part in the co-operative study of sun-spot spectra initiated by the International Solar Union.

The photographs not only show many new spot lines; some of them also bring out for the first time bright reversals similar to those observed visually by Mitchell. Since such reversals may prove of great importance in the interpretation of spot spectra, they will receive careful attention.

Besides serving for the photography of spot spectra by Mr. Adams and myself, the tower telescope has enabled us to continue and extend our comparative study of the spectra of the limb and center of the sun. Moreover, the remarkable results obtained by Mr. Adams in his spectrographic determination of the rotational motion of hydrogen in the sun[1] were derived from photographs made with the 30-foot spectrograph. As for work with the spectroheliograph, I have been confined, pending the completion of the 30-foot instrument, to preliminary

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 24.

experiments with the spectroheliograph attachment of the 30-foot spectrograph. With the aid of a 5-inch grating, which is very bright in the first order, I have secured a few photographs of sun-spot regions with iron and hydrogen lines. These show that a long-focus spectroheliograph of the Littrow form will give excellent results. The use of two camera slits, permitting photographs of the same region to be taken simultaneously with different lines, has been tested and found to be very satisfactory. This method is indispensable for accurate comparisons of the forms and positions of the flocculi of different elements, and will find many applications in our future work.

FEBRUARY 1908

PRELIMINARY NOTE ON THE ROTATION OF THE SUN AS DETERMINED FROM THE DISPLACEMENTS OF THE HYDROGEN LINES[1]

By WALTER S. ADAMS

In the course of the investigation of the relative displacement of the spectrum lines at the sun's limb, first found by Halm,[2] and confirmed by Professor Hale and myself, a number of plates have been secured including the principal hydrogen lines in the visible spectrum. Since hydrogen extends to a great height in the solar atmosphere, it seems probable that the vapor which contributes to the formation of the hydrogen lines in the solar spectrum lies at a generally higher average level than that giving rise to the greater part of the Fraunhofer lines. Accordingly, if the displacements at the sun's limb are due to pressure, and our results show this almost certainly to be the case, the hydrogen lines might be expected to show smaller displacements than the majority of the lines in the spectrum. To test this question a number of measures upon $H\alpha$ have been made, and the displacements have, in fact, been found to be extremely small, the mean value derived from several plates amounting to less than 0.001 Ångström.

In addition, however, to furnishing results for the pressure-shifts of the hydrogen lines at the sun's limb, the measures of the plates give the displacements due to the rotation of the sun. Since each exposure consists of a spectrum of the limb with a spectrum of the center of the sun on either side for reference, and points on the limb 180° apart are taken alternately, it is evident that if δ is the displacement between center and west limb, for example, and δ' the displacement between center and east limb, both taken regardless of sign,

$$\frac{\delta-\delta'}{2}$$

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 24.

[2] *Astronomische Nachrichten*, 173, 273, 1907.

will be the shift due to pressure, and

$$\frac{\delta+\delta'}{2}$$

will be the shift due to the rotation of the sun. When the values of $\delta+\delta'$ for $H\alpha$ and for the other lines measured were compared, the interesting result was found that in the case of $H\alpha$, $\delta+\delta'$ was considerably larger than for the other lines in its vicinity. Since the plates available were necessarily taken at latitudes on the sun defined by the directions in which the image of the sun could be moved across the slit of the spectrograph, it seemed desirable to continue the work with apparatus which would make it possible to obtain a greater range of latitudes, and accordingly the later plates were taken with the regular rotation attachment employed with the 30-foot spectrograph of the tower telescope. With this instrument any desired position angle on the sun's surface may be brought upon the slit by motion about a vertical axis.

In a previous paper[1] reference was made to the remarkable differences in the behavior of the hydrogen lines at the limb of the sun. It was found that $H\alpha$ was much widened and probably strengthened at the limb as compared with its intensity at the center of the sun, $H\beta$ was similarly affected, though to a less extent, while $H\gamma$ and $H\delta$ were slightly narrowed and weakened. In sun-spots no such exceptions are found, all of the lines being greatly narrowed and reduced in intensity. A few measures upon the widths of $H\alpha$ and $H\gamma$ at center and limb indicate the difference in the behavior of these two lines.

	Width at Center	Width at Limb
$H\alpha$	0.90 Ångström	1.15 Ångström
$H\gamma$	0.46	0.44

The width of $H\alpha$ given in Rowland's table is 0.95 Ångström, the agreement with which is quite satisfactory for measures necessarily as difficult as these.

The plates used in the determinations given here include $H\alpha$, $H\gamma$, and $H\delta$. The nature of the line $H\beta$ is such as to make it practically impossible to use it in work involving accurate measurements. The plates of $H\alpha$ have been made in the second order of the grating, and

[1] Hale and Adams, *Contributions from the Solar Observatory*, No. 17; *Astrophysical Journal*, **25**, 300, 1907.

those of $H\gamma$ and $H\delta$ in the third. In spite of the difference in scale, however, the values given by $H\alpha$ are much the most accurate of the three, owing to the quality of the line. In fact, the values for $H\gamma$ and $H\delta$ are relatively so poor that it is doubtful whether they add appreciably to the accuracy of the mean result. The complicated structure of $H\delta$, owing probably to the presence of foreign lines, is well known, and has given rise to an uncertainty in the value of its wave-length amounting to 0.1 Ångström. The wave-length derived from these measures is 4101.91.

The measures have been made by Miss Lasby of the Computing Division and myself, and are tabulated separately in order to furnish some idea of the degree of accordance attained. It is hardly necessary to call attention to the fact that the accuracy is of quite a different order from that which can be secured with the sharp and narrow lines of the solar spectrum. The difficulties arising from the great width of the lines can, if necessary, be overcome to some extent by the use of broad wires in the measuring microscope, but those due to haziness, complications of structure, and lack of symmetry, are very serious, and give great trouble. Fortunately, the lines between which the displacements are measured are identical in appearance, and the effect of errors of judgment in the estimation of the position of the centers of the lines becomes differential rather than absolute.

In the tables ϕ as usual denotes the latitude, and the velocities given are in kilometers per second. The values are those which are observed directly, before reduction for the earth's motion. The letter L. indicates the measures of Miss Lasby and A. those of the writer.

Plates ω 99, ω 101, and ω 102 contain in some cases two exposures for the same latitude, the mean of which is given in the table. If we

$H\alpha$

ϕ	ω 96		ω 101		ω 102	
	L.	A.	L.	A.	L.	A.
− 0°.1	2.06	2.08	2.07	2.05	2.14	2.09
9.3			2.01			
14.8	1.94	2.00	1.96	1.99	2.00	1.99
22.7	1.88	1.91				
29.6	1.62	1.71	1.85	1.74	1.76	1.76
44.5	1.45	1.45	1.51	1.40	1.46	1.46
59.2	1.05	1.01	0.99	0.95	0.95	1.08
73.4	0.73	0.66	0.66	0.56	0.70	0.58

$H\gamma$			$H\delta$		
ϕ	ω 99	ω 103	ϕ	ω 99	ω 103
	A.	A.		A.	A.
0°0........	2.05	2.06	0°0.......	2.05	2.07
14.9........	1.89	1.94	14.9.......	1.96	1.98
29.8........	1.72	1.65	29.8.......	1.70	1.74
44.6........	1.42	1.40	44.6.......	1.47	1.38
59.4........	1.07	1.11	59.4.......	1.16	0.99
73.6........	0.60	0.66	73.6.......	0.59	0.58

assign these values double weight, and form means for the separate lines, we obtain the following results:

ϕ	$H\alpha$	$H\gamma$	$H\delta$
	km	km	km
− 0°1........	2.09	2.05	2.06
9.3........	2.01	....	....
14.8........	1.98	1.91	1.97
22.7........	1.90	....	....
29.7........	1.75	1.70	1.71
44.6........	1.46	1.41	1.44
59.3........	1.00	1.08	1.10
73.5........	0.64	0.63	0.58

There seems to be some tendency for $H\alpha$ to give values larger than those furnished by the other two lines, and a result of this sort would seem to be by no means impossible in view of the marked difference in its behavior as regards width and intensity. Until additional material, however, is available, particularly for $H\gamma$ and $H\delta$, it is hardly justifiable to consider this difference in velocity as real, or to draw conclusions from it.

The result of forming a general mean of all the observations is given in the table below. The column $v+v_1$ gives the linear velocity corrected for the earth's motion, and ξ as usual denotes the angular velocity. The period in days corresponding to the angular velocity is given in the succeeding column. It is evident that the points at latitudes 9°3 and 22°7 are of very low weight, the first being based upon only a single measure, and the second upon but two. The last two columns give the values of the angular velocity and the period for the reversing layer, and are taken from an earlier paper on the rotation of the sun.[1]

[1] Adams, *Contributions from the Solar Observatory*, No. 20; *Astrophysical Journal*, **26**, 203–24, 1907.

ϕ	v	$v+v_1$	ξ	Period	ξ'	Period
	km	km	km	days		days
$-0^\circ.1$......	2.07	2.21	$15^\circ.7$	22.9	$14^\circ.7$	24.5
9.3......	2.01	2.15	15.5	23.2	14.5	24.8
14.8......	1.96	2.10	15.4	23.4	14.4	25.9
22.7......	1.90	2.03	15.6	23.1	13.9	25.9
29.7......	1.73	1.87	15.3	23.5	13.7	26.3
44.5......	1.44	1.55	15.4	23.4	12.8	28.1
59.3......	1.04	1.12	15.6	23.1	12.2	29.5
73.5......	0.63	0.67	16.7	21.6	11.8	30.5

Two important conclusions are at once evident from an examination of these results. The first is that the rotational velocity of the hydrogen gas is decidedly higher than that of the general reversing layer, amounting at the equator to 1° in the angular motion. A result of this kind was perhaps to be expected in view of the differences found among the different lines studied in the previous investigation.[1] It was there shown that lines due to lanthanum and cyanogen, both of which are known to lie at a low level in the solar atmosphere, gave consistently small values for the rotational velocity, although the difference was slight. Similarly, two or three other lines gave systematically large values. The conclusion seems to be unavoidable that what we may call the "effective" level of the vapors, the integrated action of which gives rise to the hydrogen lines at the sun's limb, lies very high in the sun's atmosphere, and that at this higher level the angular velocity is considerably greater than in the region close to the photosphere.

A second conclusion to be drawn from these results is also of great importance. It is that at the level of the hydrogen gas at which the spectrum lines are formed the law of the sun's equatorial acceleration has ceased to hold. An examination of the table shows that the values of ξ for the various latitudes, with the possible exception of $73^\circ.5$, are constant to within less than might perhaps have been expected from the internal agreement of the measures. Even at the highest latitude the value of the angular velocity is so sensitive to a slight difference in linear velocity that the discordance in the value of ξ is by no means excessive. In fact, a difference in the value of $v+v_1$ of less than 0.05 km would be sufficient to bring the value of ξ into agreement with

[1] Adams *loc. cit.*

the results for the other latitudes, and such an error would not be at all abnormal in determinations of this sort.

The rather fundamental character of these results will, of course, lead to a continuation of the investigation, and to an extension of the measures to include lines of other elements, particularly sodium, and, if possible, calcium. In some such way it would seem not improbable that an upper limit may be set to the region within which the law of the sun's equatorial acceleration continues to hold.

Mount Wilson, California
February 1908

PRELIMINARY NOTE ON THE ROTATION OF THE SUN AS DETERMINED FROM THE MOTIONS OF THE HYDROGEN FLOCCULI[1]

By GEORGE E. HALE

The first photographs of the hydrogen flocculi were taken with the Rumford spectroheliograph of the Yerkes Observatory in May 1903. Several reproductions of negatives obtained during that year, accompanied by a brief discussion of the nature of the flocculi, were published in a paper on the Rumford spectroheliograph by Mr. Ellerman and myself.[2] With the instrument employed, it was then possible to photograph only comparatively narrow zones of the solar image by hydrogen light. For this reason the study of the hydrogen flocculi was necessarily confined to their physical nature and their relationship to other solar phenomena.

The completion of the Snow telescope and the 5-foot spectroheliograph made it possible to include systematic records of the hydrogen and iron flocculi, in addition to those of calcium, in the daily series of photographs commenced on Mount Wilson in October 1905. Since the entire solar image is shown in all photographs of this series, the negatives are suitable for the determination of the heliographic positions and daily motions of the hydrogen flocculi. Two heavy flint-glass (Schott No. 0.102) prisms, each of 63° 29′ angle, are employed in the spectroheliograph, with collimator and camera objectives of 5 feet (152 cm) focal length, giving sufficient dispersion to permit good photographs to be made with the $H\delta$ line. On account of the demands of the routine work, comparative studies of the hydrogen flocculi with the $H\alpha$, $H\beta$, and $H\gamma$ lines were postponed until the 30-foot spectroheliograph of the tower telescope could be applied to this purpose.

The material available for the determination of the motions of the hydrogen flocculi comprises a large collection of photographs, covering the period from October 1903 to the present date. On every

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 25.

[2] *Publications of the Yerkes Observatory*, Vol. III, Part 1.

clear day hydrogen photographs are made both in the early morning and the late afternoon. It is fortunate for the present purpose that no greater time-interval separates the successive plates, since the rapid changes in form of the hydrogen flocculi make the identification of objects for measurement the most difficult part of the investigation. These rapid changes are associated with proper motions much larger than those observed in the case of the calcium flocculi. It was partly for this reason that a systematic study of the hydrogen flocculi was deferred until the completion of an extensive investigation of the calcium plates. The difficulties of identification and measurement offered by the calcium flocculi, while much less serious, afford just the practice required in preparation for work on the hydrogen plates.

A few identifications and measurements of hydrogen flocculi were nevertheless made in order to test the available material, and to ascertain its fitness for work on the solar rotation. This preliminary examination of the plates left no doubt as to the rapid changes of form and the large proper motions peculiar to the hydrogen flocculi. It also indicated that the rotational velocities, at least in the higher latitudes, would probably be greater than in the case of the calcium flocculi.

After Mr. Adams' recent spectrographic work had shown the high equatorial velocity of hydrogen, as determined by the relative displacement of lines observed at points very near the east and west limbs of the sun, it became a matter of great interest to continue, along two entirely independent lines, the investigation of the rotational motion of this gas. Accordingly, Mr. Adams extended his observations to higher latitudes, with the extremely interesting results given in another paper.[1] At the same time Miss Ware undertook the measurement, with the heliomicrometer, of a sufficient number of hydrogen plates to afford a preliminary determination of the motions of the flocculi. Although a much more extensive study will be required to give definitive results, there seems to be no doubt that the motions of the hydrogen flocculi differ appreciably from those of the calcium flocculi, and indicate the operation of a different law of rotation.

[1] Adams, *Contributions from the Mount Wilson Solar Observatory*, No. 24, *Astrophysical Journal*, 27, 213, 1908.

The results given below were derived from 547 measures of hydrogen flocculi on 20 different plates, the numbers and dates of which are given in Table I. The intervals separating the successive plates

TABLE I

Plate No.	Date	Plate No.	Date	Plate No.	Date
	1906		1906		1906
507	July 1, 6:55 A. M.	867	Aug. 24, 6:43 A. M.	1086	Sept. 21, 4:38 P. M.
510	July 1, 5:30 P. M.	868	Aug. 24, 5:16 P. M.	1090	Sept. 22, 7:14 A. M.
514	July 2, 6:40 A. M.	874	Aug. 25, 6:36 A. M.		1907
516	July 2, 5:37 P. M.	881	Aug. 26, 6:59 A. M.	2392	July 30, 7:08 A. M.
519	July 3, 6:38 A. M.	885	Aug. 26, 5:24 P. M.	2396	July 30, 5:46 P. M.
854	Aug. 23, 6:28 A. M.	1075	Sept. 20, 4:47 P. M.	2429	Aug. 3, 6:37 A. M.
861	Aug. 23, 5:16 P. M.	1080	Sept. 21, 6:53 A. M.	2433	Aug. 3, 5:36 P. M.

varied from 10 to 14.5 hours. In the case of three photographs (Nos. 1080, 1086, and 1090), taken within an interval of about twenty-four hours, two of the plates showed the presence of systematic errors, the latitudes of corresponding points differing by amounts which increased regularly from the equator toward the north pole, and decreased in the same regular manner toward the south pole. As it was evident that the effect must be due to errors in the orientation of the plates, values for the orientation, differing 1.0 and 1.5 respectively from the calculated values, were assumed. The magnitudes of these corrections were so chosen as to eliminate the observed systematic deviations in latitude. In applying these corrections, no attention was paid to their effect upon the longitudes. If we omit the measures of the flocculi secured with the aid of these plates we obtain the values of ξ' given in the fourth column of the table.[1]

Table II gives the number of measures of hydrogen flocculi in five-degree zones, and the mean angular rotations, ξ, reduced from synodic to sidereal values. The means combine the results for corresponding zones in the northern and southern hemispheres. The

[1] The orientation of spectroheliograph plates made with the Snow telescope is determined by the aid of test plates, on which the solar image is photographed several times after being allowed to drift a certain distance between successive exposures. These test plates are made for various settings of the coelostat (east and west) and second mirror (north and south), the positions being determined by the aid of scales provided for the purpose. It has occasionally happened, as in the present instance, that a test plate, for the particular settings of the two plane mirrors, was not made within a sufficiently short interval of the actual time of observation, thus introducing such an error of orientation as that mentioned above.

TABLE II

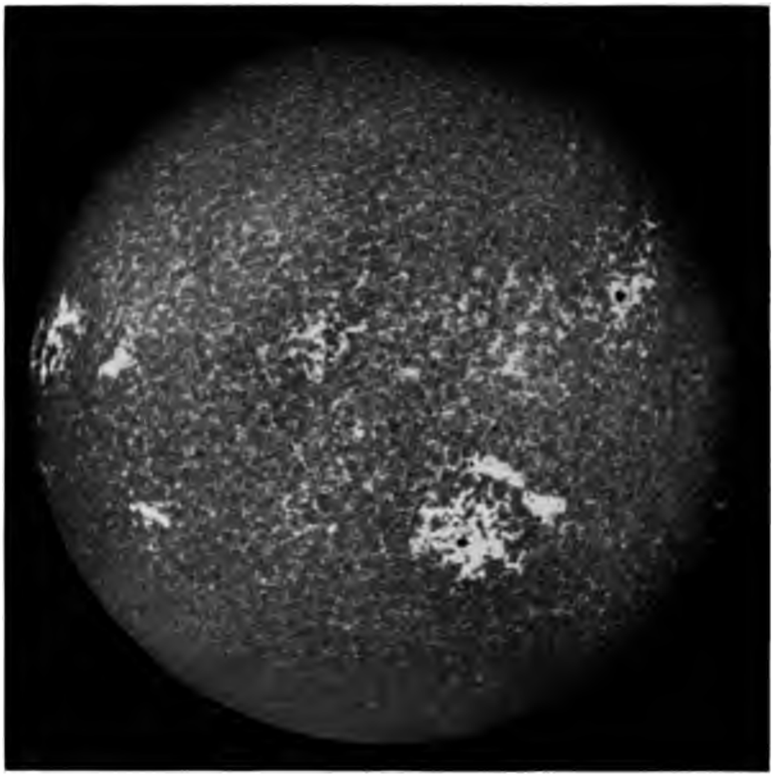
Zone	Hydrogen ($H\delta$)			Calcium (H_2)		
	No. of Measures	ξ	ξ'	No. of Measures	ξ	ξ''
0 ± 5	91	14°3	14°4	232	14°5	14°5
± 5 ±10	77	14.4	14.6	262	14.3	14.3
±10 ±15	95	14.6	14.7	317	14.3	14.3
±15 ±20	73	14.5	14.5	326	14.2	14.2
±20 ±25	71	14.7	14.7	259	14.2	14.2
±25 ±30	65	14.7	14.6	153	14.0	14.1
±30 ±35	33	14.9	15.0	99	13.8	13.8
±35 ±40	23	14.6	15.0	26	14.0	13.9
±40 ±45	19	14.4	14.3	6	13.2	13.2

fourth column (ξ') has already been explained. In the next two columns are given, for comparison, the number of measures in each zone and the values of ξ derived from the measurement of 1,680 calcium (H_2) flocculi on 51 negatives taken with the Snow telescope and 5-foot spectroheliograph, during the period June 18–September 22, 1906. These are the preliminary results of a study of the motions of the calcium flocculi, which involves the measurement of about 30 more plates, now nearly completed by Miss Ware. The last column, ξ'', contains the results for calcium obtained with the same number of measures used for hydrogen (except in the zone 40°–45°, where only 6 measures were available). The internal agreement of the measures indicates that these means for the calcium flocculi are, in general, about twice as precise as those for the hydrogen flocculi.

All of the work of measurement has been done with the heliomicrometer.[1] In the case of calcium, settings are made with the cross-hairs on flocculi previously identified by comparison with the preceding or following plate. The hydrogen flocculi offer greater difficulties, not only because of their rapid changes, but also because of their small contrast on the photographs. Two negatives are compared in the Zeiss stereocomparator, with the aid of the monocular attachment. Great pains are taken in making the identifications, all doubtful cases being rejected. Small nuclei, which are rather darker than the average flocculi, seem to be the most persistent objects, and are usually selected for measurement. These are marked on the glass

[1] Hale, *Contributions from the Solar Observatory*, No. 16; *Astrophysical Journal*, 25, 293, 1907.

PLATE XV



THE SUN, SHOWING THE CALCIUM (H_2) FLOCCULI
1906, August 25, 6^h 18^m A. M., Pacific Standard Time

side of the negative with dots of ink, and the positions of these dots are measured with the heliomicrometer. The flocculi themselves are too faint for measurement, and the errors due to large proper motions are far greater than any which can arise from this procedure.

In the case of the calcium flocculi the existence of the equatorial acceleration is clearly evident. The hydrogen flocculi, however, show no systematic variation of ξ with the latitude. As already remarked, the hydrogen measures are less reliable than those of calcium, because of the inclusion of a much smaller number of flocculi, larger proper motions, and more rapid changes of form. We may therefore take the mean value of ξ for all the zones ($14.^\circ 6$) as a provisional determination of the daily angular motion of the hydrogen flocculi.

The provisional results here given for the motions of the hydrogen flocculi, though of rather low weight, are of importance when taken in connection with Mr. Adams' spectrographic determinations.[1] Both methods agree in showing that the hydrogen in the sun does not share the equatorial acceleration observed in the case of sun-spots, faculae, calcium flocculi, and reversing layer. The simplest way to account for this difference is on the assumption that the hydrogen whose motion is measured lies at a higher level. As this raises the question of the nature of the flocculi and their levels as compared with those of the spots and faculae, it may be advantageous to review briefly the evidence afforded by existing observations, and to mention some of the observations required to clear up obscurities.

Let us first consider the calcium flocculi photographed with the spectroheliograph when the camera slit is set on one of the bright lines H_2 or K_2 (Plate XV). With radial slit these bright lines project at the limb well into the chromosphere, retain considerable width for a few thousand miles, and then narrow down to the width of H_3 and K_3. Since H_2 flocculi frequently cover sun-spots, and are sometimes photographed as projections at the sun's limb, we may safely say that their average level is that of the lower chromosphere. The photometric measurement of the relative intensities of H_2 flocculi and the adjoining photosphere, at various distances from the limb, should assist in defining their level more closely.

[1] *Loc. cit.*

When the camera slit of a spectroheliograph is set on H_1 or K_1, bright regions, smaller in area and finer in detail than the H_2 flocculi, appear on all parts of the solar disk (Plate XVI). The forms of these H_1 flocculi agree closely with those of the faculae in direct photographs of the sun, and it is still uncertain in what relative degree the continuous spectrum of the faculae and the light of the low-lying dense calcium vapor contribute toward their formation. To settle the question the following methods may be used: (1) Comparisons of the forms and positions of H_1 flocculi and faculae, photographed simultaneously with a spectroheliograph having two camera slits; (2) Photometric determinations of the intensity-curves of H_1 and K_1 in photographs of the spectra of faculae and the adjoining photosphere; (3) Photometric measurements, on spectroheliograph plates, of the relative intensity of faculae and H_1 flocculi at various distances from the limb.

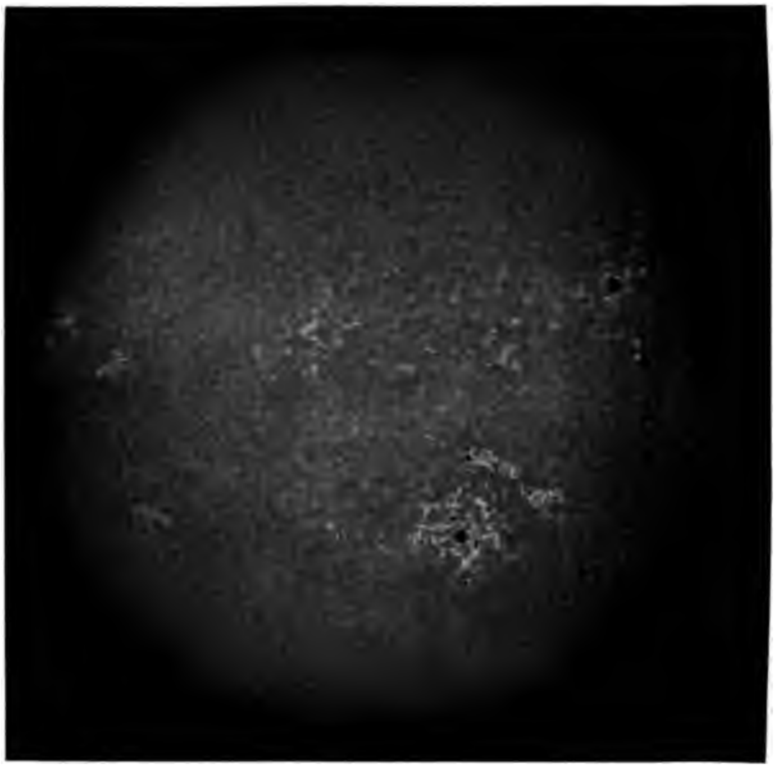
Pending further work on this subject, we need have little hesitation in ascribing to the H_1 flocculi a level coinciding with or slightly above that of the faculae, and below that of the H_2 flocculi.

As for hydrogen, the reasons which led to the belief that its dark flocculi represent, on the average, a relatively high level, are given in the paper already mentioned.[1] Since that time the accumulation of evidence has only tended to strengthen this belief. It has been found, for example, in comparing the relative distances from the sun's limb of corresponding calcium and hydrogen flocculi, that the latter are, in general, displaced toward the limb by a very appreciable amount. The displacements vary greatly for different flocculi, but the average difference of level represented may be roughly stated as from one to two thousand miles. On account of the effect of atmospheric disturbances, however, an accurate determination of this difference of level cannot be made until photographs taken simultaneously with H_2 and one of the hydrogen lines become available.

In addition to the direct evidence afforded by these displacements, we have other evidence which also seems significant. It was found at the Yerkes Observatory that exceptionally dark hydrogen flocculi are frequently represented on calcium (H_2) plates by dark objects, roughly corresponding with them in form. Our Mount Wilson

[1] *The Rumford Spectroheliograph of the Yerkes Observatory*, p. 20.

PLATE XVI



THE SUN, SHOWING THE CALCIUM (H_1) FLOCCULI
1906, August 25, 6^h 22^m A. M., Pacific Standard Time

records show a great number of these dark calcium flocculi, which appear to be invariably associated with exceptionally dark hydrogen flocculi. Mr. Ellerman has photographed the spectra of these objects and found that the marked strengthening and widening of their hydrogen lines is accompanied by a similar strengthening and widening of H_3 and K_3. This indicates that these hydrogen flocculi are at the H_3 level, rather than in the lower region of denser calcium vapor represented by H_2. When describing the work of the Kodaikanal Observatory before the Royal Astronomical Society, Mr. Michie Smith stated that these dark calcium flocculi, when photographed near the limb, are found to agree in position with prominences. This is in harmony with similar results obtained at the Yerkes Observatory, and leaves little room for doubt that some of the dark hydrogen flocculi are prominences photographed in projection on the solar disk. It is probable, however, that the less conspicuous dark hydrogen flocculi occupy a lower level, at or somewhat below the upper part of the chromosphere.[1] Thus the assumption that the dark hydrogen flocculi are high-level phenomena (as compared with the H_2 calcium flocculi), which was at first made simply to account for their darkness, on the ground that absorption effects would be most likely to present themselves in the higher and cooler gases, seems to be borne out by the evidence just cited.

The results obtained from the study of the rotational velocity of the hydrogen flocculi may now be considered in this connection. If these flocculi, on the average, are at a higher level than the H_2 calcium flocculi, the difficulty of ascribing to them a different rate and law of rotation is greatly decreased. In Wilsing's theoretical discussion of the law of the solar rotation,[2] the important effect of internal friction is given special consideration. On account of this friction, Wilsing assumes that the differences of angular velocity "must diminish as the center of the sun is approached, until a surface is reached, the particles of which rotate with sensibly constant angular velocity about a common axis." Above the photosphere there may be considerable

[1] It is of course supposed that the hydrogen extends down to the base of the chromosphere, but that the region of effective absorption, represented by the dark flocculi on the spectroheliograph plates, is at the level mentioned.

[2] *Astrophysical Journal*, 23, 247, 1906.

internal friction at the base of the chromosphere, but this friction must decrease rapidly in going outward. Finally, Wilsing assumes, a spherical surface will be reached which, like the inner one, rotates with uniform velocity.

Through the effect of friction the different rotational velocities observed by Mr. Adams in the case of lines of different elements find ready explanation.[1] Carbon and lanthanum, which give values for the daily rate about $0^\circ\!.1$ less than the mean result for all the lines employed, are elements which lie at a low level in the solar atmosphere. We now find that the dark hydrogen flocculi, to which a high level in the chromosphere has been independently ascribed, show no evidence of equatorial acceleration.

Table III brings together the results of various determinations of the solar rotation, as indicated by the motions of sun-spots, faculae, reversing layer, calcium and hydrogen flocculi, and hydrogen. Carrington's spot values are taken from his *Observations of the Spots on the Sun.* Spoerer's are computed from his formula

$$\xi = 8^\circ\!.548 + 5^\circ\!.798 \cos b\ ,$$

where b is the latitude.[2] Maunder's values of ξ are derived from his formula

$$\xi = 866'\!.6 \pm 128' \sin^2 \lambda$$

where λ is the latitude.[3] The results given for the faculae are due to Stratonoff,[4] while those for the calcium flocculi include the Kenwood spectroheliograph results,[5] Mr. Fox's Rumford spectroheliograph results for 1903–4,[6] and the Mount Wilson results for 1906 (Table II). The values for the reversing layer are those of Mr. Adams.[7] For the hydrogen flocculi and for hydrogen (spectrographic),[8] mean

[1] *Contributions from the Solar Observatory*, No. 20, p. 13; *Astrophysical Journal*, **26**, 247, 1907.

[2] *Potsdam Publications*, Vol. X, Part 1.

[3] *Monthly Notices*, **65**, 823, 1905.

[4] *Mem. Acad. de St. Pétersbourg*, Vol. V, No. 11.

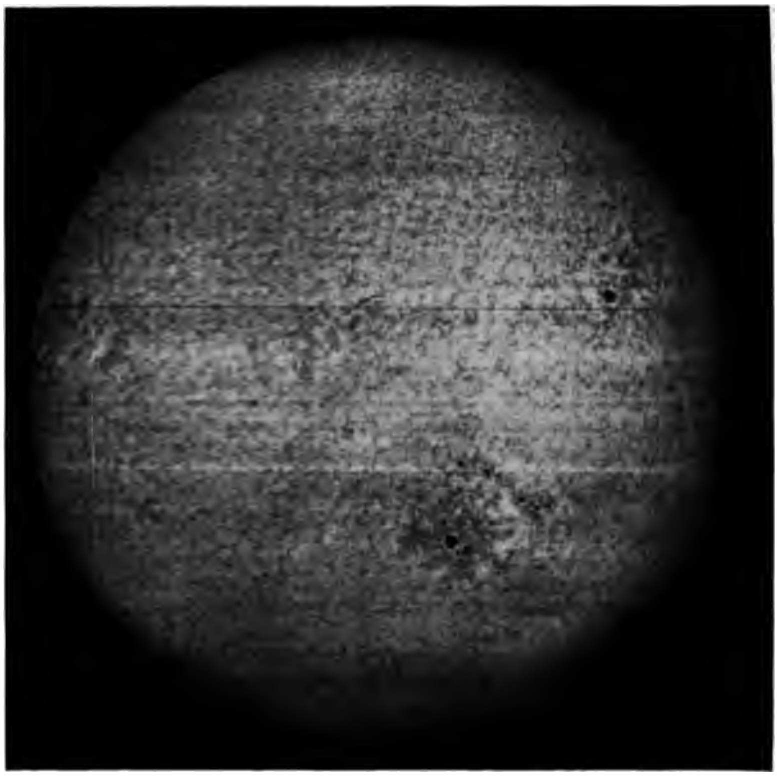
[5] Hale and Fox, *The Rotation of the Sun, as Determined from the Motions of the Calcium Flocculi* (in press).

[6] *Science*, April 19, 1907.

[7] *Loc. cit.*

[8] Adams, *Contributions from the Mount Wilson Solar Observatory*, No. 24; *Astrophysical Journal*, **27**, 213, 1908.

PLATE XVII



THE SUN, SHOWING THE HYDROGEN ($H\delta$) FLOCCULI
1906, August 25, 6^h 36^m A. M., Pacific Standard Time

TABLE III

	Spots				Faculae Stratonoff	Reversing Layer Adams	Calcium Flocculi (H_2)				Hydrogen Flocculi ($H\delta$)	Hydrogen (Spectrographic)
	Carrington	Spoerer	Maunder	Unweighted Means			Kenwood	Fox 1903–4	Mount Wilson	Unweighted Means		
0 ± 5	14°42	14°34	14°44	14°40	14°62	14°70	14°66	14°49	14°46	14°54	14°6	15°5
± 5 ± 10	14.35	14.30	14.41	14.35	14.61	14.58	14.52	14.42	14.30	14.41		
± 10°± 15	14.21	14.21	14.34	14.25	14.31	14.43	14.37	14.24	14.30	14.30		
± 15°± 20	14.06	14.08	14.25	14.13	14.18	14.23	14.22	13.94	14.22	14.13		
± 20 ± 25	13.90	13.90	14.13	13.98	14.19	14.00	14.12	13.67	14.19	13.99		
± 25 ± 30	13.73	13.69	13.99	13.80	14.08	13.72	13.90	13.96	14.04	13.97		
± 30°± 35	13.54	13.44	13.83	13.60	13.60	13.43	13.76	13.70	13.80	13.75		

velocities, including all the results obtained within 40° of the equator, are taken as most representative.[1]

The results show no such difference between the rotational velocities of spots and calcium flocculi as the higher level of the latter would lead us to expect. The large values of ξ for the faculae are not easily explained, but the difficulties involved in their measurement necessarily render them somewhat uncertain. The high spectrographic velocities of the reversing layer and of the hydrogen above it arouse the suspicion that the spots, faculae, and flocculi do not move as rapidly as the gaseous medium in which they float, possibly because they retain the velocities of lower levels, from which the faculae and flocculi, if not the spots, may rise. The great speed of hydrogen may be due, however, to the fact that the gas most effective in the production of the hydrogen lines at the limb lies at a level above that of the hydrogen flocculi.[2] In the hope of clearing this up spectrographic observations will be made at points on the disk within the region where the motions of the hydrogen flocculi have been measured.

The importance of improving and extending the above results calls for more work of a varied character. A vigorous attempt should be made to determine the level of sun-spots, by the spectroheliograph method suggested elsewhere[3] or by other means. Extensive observations of the faculae are especially needed, as the difficulty of securing accurate measures of objects photographed only in the neighborhood of the limb must be recognized. This work can be most usefully supplemented by an investigation of the motions of the H_1 flocculi, particularly if the above-mentioned methods of testing their relationship to the faculae are put into practice. The spectrographic observations should be extended to other lines, special attention being devoted to hydrogen, calcium, sodium, and magnesium. Observers with spectroheliographs are strongly urged to adapt their

[1] In a future paper certain data not now available, including the latest spectrographic results of Dunér and Halm and additional observations of the calcium flocculi by Fox, will be used in a general discussion of the solar rotation.

[2] As $H\alpha$ seems to give higher spectrographic velocities than $H\gamma$ and $H\delta$, besides being greatly strengthened (while the others are almost unchanged) at the limb, some of the difference may possibly be due to this cause.

[3] *Report of the Director of the Mount Wilson Solar Observatory, for the Year ending September 30, 1907.*

instruments for the photography of the hydrogen flocculi, as many measurements of these objects are required. Indeed, the interpretation of the phenomena presented by these flocculi, other than those connected with their rotation, offers in itself a large field for research.

Since anomalous dispersion phenomena might be expected to arise under just such conditions as are here assumed to obtain in the flocculi, the possibility of their existence must not be ignored. It is hoped that investigations now in progress here will throw some light on this fundamentally important question.

Mount Wilson Solar Observatory
February 1908

ON THE ILLUMINATION OF THE DARK SIDE OF *SATURN'S* RINGS

By HENRY NORRIS RUSSELL

Professor Barnard's recent discovery[1] that, when the shaded side of *Saturn's* rings is turned toward us, the line of light which we see is the faintly illuminated surface of the rings, and not their sunlit edge, suggests that their visibility is due to light reflected from the ball of the planet.

This theory was advanced a century ago by Herschel, and later discussed by Bond,[2] who concluded that the illumination would be too faint to be seen. But the photometric data now available concerning the sun and planets, together with Barnard's observations, make it possible to give this theory a more exact test, with more favorable results.[3]

Of the two pairs of condensations seen upon the line of the rings, the outer ones fall upon the brightest part of the inner ring, "which" says Barnard, "is much the brightest portion of the entire ball and ring system." Their distance from *Saturn's* center is almost exactly equal to the planet's polar diameter. An observer on the surface of the ring at this point would see one-half of *Saturn's* disk, whose polar diameter would be 60°. If this was fully illuminated, the light which he would receive from it would surpass that which we get from *Saturn* in the ratio of the apparent areas of the planet's visible surface in the two cases. At mean opposition the polar diameter of *Saturn* is $18''.14$, so that this ratio is $\frac{1}{2}\times\frac{\sin^2 30^\circ}{\sin^2 9''.07}$ or 6.47×10^7, which corresponds to 19.53 stellar magnitudes. The mean magnitude of *Saturn* at opposition (without the ring) being 0.88, we find that the illumination at the distance of the condensations is represented by the magnitude -18.65. The magnitudes of the sun and mean full moon, as seen from the earth, are -26.60 and -11.77;

[1] *Astrophysical Journal*, **27**, 35–44, 1908.

[2] *Harvard Annals*, **2**, 112–14.

[3] The photometric data which follow are taken from Müller's *Photometrie der Gestirne*, Leipzig, 1897; the other data are Barnard's.

so that we find that the intensity of the light reflected from *Saturn* is 560 times our moonlight, and $\frac{1}{1800}$ of our sunlight, or 1/16.6 of sunlight on *Saturn* at its mean distance (9.539).

For an observer on *Saturn's* surface in the shadow of the ring, its "dark" side would therefore be a very conspicuous object (which, because of its great area, would send him more moonlight than all the satellites put together).

But the observed condensations are at the ansae, and, viewed from them, *Saturn* would appear "as a half-moon half set"—in Bond's expressive phrase. The separate particles of which the ring is composed, being illuminated from one side by the planet, would also appear to us (could we see them individually) something like half-moons, although, owing to the great angular diameter of *Saturn* as seen from them, more than half of their surface would be illuminated.

Now a half-moon is not nearly half as bright as a full moon, the difference depending on the physical constitution of its surface. The moon is only $\frac{1}{7}$ as bright at the quarter as at full. The corresponding factor for *Venus* is $\frac{1}{4}$, while the theoretical laws of diffuse reflection from a smooth surface point to a ratio of about $\frac{1}{3}$. *Saturn* (which, like *Venus*, has a very high albedo) probably resembles *Venus* in this respect also, and differs from it, if at all, in the opposite way from the moon.

We may therefore estimate the intensity of the light reflected from *Saturn* to the condensations at the ansae as $\frac{2}{7}$ of what we have calculated on the assumption of full illumination.

The effective reflecting power of the ring particles (which are also of high albedo and are more than half illuminated) may be estimated as about $\frac{1}{3}$ of that of the full phase (which they would show with direct sunlight).

The apparent surface brightness of the condensations, illuminated by reflection from *Saturn* alone, may thus be estimated at $\frac{1}{10}$ of that due to full illumination by the planet under the most favorable conditions or about 1/160 of the effect of direct sunlight.[1]

Now the dimensions of the condensations are $2''.3 \times 0''.5$, while

[1] Bond finds (*loc. cit.*) a much smaller value, probably because he assumed the albedo of *Saturn* to be equal to that of the moon, whereas it is actually nearly six times as great. He gives few details of his calculation.

those of *Saturn's* disk are 17.78 / 16.72. The apparent area of one of the condensations is about [illegible] that of the planet, and if the two were of the same albedo, and both illuminated by direct sunlight, the light of the condensations should be 6 magnitudes fainter than that of *Saturn*. But their illumination by reflected light is 160 times, or 5½ magnitudes fainter than by sunlight. This would make them 11½ magnitudes fainter than *Saturn*. But the part of the ring on which they are situated is very much brighter than the ball of the planet, under equal illumination. We may therefore expect the actual difference of magnitude to be between 10 and 11 magnitudes.

According to Barnard's observations, the condensations appeared distinctly brighter than *Mimas*, *Enceladus*, or *Tethys* (and presumably fainter than *Rhea*). The differences of magnitude between these satellites and their primary, as determined by Pickering,[1] are 11.9, 11.4, 10.5, and 9.9, respectively. The observed and computed brightness of the condensations agree quite within the errors of the necessarily somewhat approximate calculation, and confirm the hypothesis on which it is based.

It might seem that this theory demands that the brightest part of the rings should be that which gets the most reflected light, i. e., the part directly in front of the planet. This would be true if the rings had a smooth, plane surface. But the particles of which they are composed, though in this region strongly illuminated by *Saturn*, turn their dark sides toward us, and we get little light from them. Similarly the particles behind the planet whose illuminated side we see almost in full, receive light from only a narrow crescent of its disk.

Calculation on this basis shows that there should be a sharp maximum of apparent brightness near the ansae of each ring. The rapid fading of the brightest part of the ring on each side of these accounts for the darker space inside the outer condensations.

The inner condensations are undoubtedly due, as Barnard suggests, to the illumination of the partially transparent crape ring by sunlight coming through it from the other side, through the gaps between the particles. Their brightness is of the order of magnitude which might be expected. At the eclipse of *Japetus* in 1889, the sun's light was found to lose about one magnitude on traversing the crape ring at an

[1] *Harvard Annals*, 11, Part II, 247.

inclination of about 10° to its plane. At the date of Barnard's drawing (December 12, 1907) the elevation of the sun above the plane of the ring was a little over 2°. Its rays had therefore to pass through nearly five times as great a thickness of the crape ring, which would cause an absorption of light of rather less than five magnitudes. The illumination of the ring by translucence should therefore be of the order of magnitude of $\frac{1}{80}$ of that by direct sunlight. As the crape ring is normally much fainter than the outer rings, this leads us to expect that the inner condensation should have about the same brightness as the outer, and this agrees with observation.

In this case there should be no phase-effect confining the brightness to the vicinity of the ansae, and these condensations were actually observed to join up to the ball with scarcely any lessening of brightness. This difference of behavior of the two pairs of condensations supports the hypothesis of different origins for their illumination. It also bears on Barnard's suggestion that the outer condensations are due to light reflected by scattered particles in the Cassini division, for this would form a nearly continuous band with much less marked condensations at the ansae.

We may therefore conclude that the outer condensations, and the general visibility of the surface of the rings, may be accounted for by their illumination by light reflected from *Saturn*, while the inner condensations are due to sunlight transmitted through the partially transparent crape ring.

It is tempting to derive an upper limit for the thickness of the rings from the fact that at no time could Barnard see any evidence of a bright rim to their faintly luminous surface. Since the edge would be illuminated by full sunlight, its surface-brightness (on our hypothesis) would be about 160 times that of the condensations, and it would be as bright as they were if its width was $\frac{1}{160}$ of $0''.5$, or $0''.003$. This corresponds to 13 miles (21km) at *Saturn's* mean distance, and it would seem that the rings must be much thinner than this.

PRINCETON UNIVERSITY OBSERVATORY
February 25, 1908

ADDITIONAL NOTES ON THE VISIBILITY OF THE DARK SIDE OF *SATURN'S* RINGS

By E. E. BARNARD

It is probable, as Dr. Russell has shown in his paper "On the Illumination of the Dark Side of *Saturn's* Rings," that sunlight reflected from the ball of *Saturn* may have had something to do with the visibility of the rings when their dark side was turned toward us. The facts indicate, however, that the principal source of illumination was sunlight percolating through the particles composing the rings. In July the minor axis of the ring ellipse was nearly three times as great as after the second disappearance in October. This was startlingly apparent in the earlier observations, when to all appearance the full surface of the ring was visible. Reflected sunlight from *Saturn* could not illuminate all of the surface of the ring thus visible.

There is one important point to which I failed to call attention in my paper in this *Journal* for January. The inner condensations were brighter in general than the crape ring has ever appeared to me. This fact must be taken into account in any attempt to connect these condensations with the crape ring.

In Lick Observatory *Bulletin No. 127* Professor Aitken measured a still closer set of condensations. These were seen here, but never with a certainty that would admit of measurement, for in nearly all cases the seeing was poor. In a sketch on July 2, 1907, an attached note says with reference to the inner condensation preceding: "Possibly here there are two condensations." This double condition of the inner condensations was also noted several times after October 4, especially on November 3 and 5. On the latter date a sketch shows this double appearance, and an attached note says, "It looks as if there were two condensations here." Another note says, "The inner condensation is certainly double in each case."

The outer condensations were almost round in the first part of November, but in December they were decidedly flattened.

The relative brightness of the outer and inner condensations

varied somewhat, but not in a very marked degree. This is indicated by some of the notes:

July 5. The inner condensations are one-half as bright again as the outer ones.

November 3. (The following ansa.) The outer condensation is the brighter. It looks as if there might be a bright point or satellite on it. $7^h\ 50^m$. The outer condensation following seems to have a small bright spot in it—a small satellite projected on the ring? After carefully examining the outer one preceding, I think it is exactly like the following one; it seems to be a small condensation in the larger one—it is almost a round spot. The inner condensations are a little the brighter, and it looks as if there were two condensations at that point.

November 5. On the following side, the inner condensation is decidedly brighter than the outer one by say ½ magnitude or more. The inner condensation is certainly double in each case.

November 12. The outer condensations seem to be perhaps a little brighter than the inner ones and may be a little larger. They are all very conspicuous. It is estimated that the outer ones are two and one-half times as long as broad. They diffuse rather abruptly on each side. Later: the outer and inner condensations seem to be of the same brightness.

In general after this, they were of equal brightness.

Yerkes Observatory
March 11, 1908

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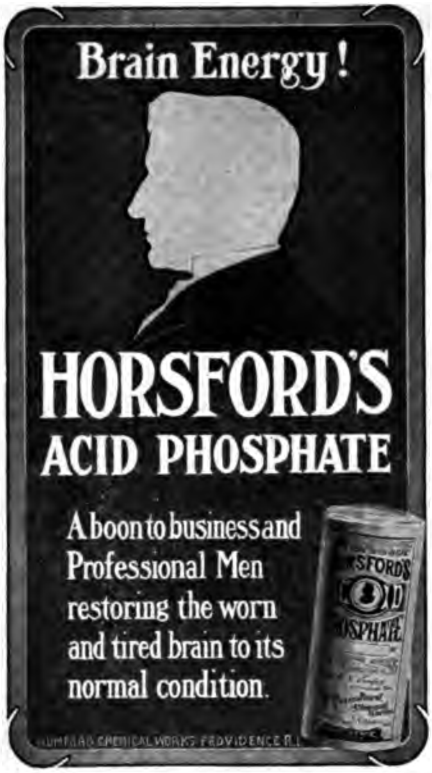

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CONTENTS

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AN INVESTIGATION OF THE FORTY-INCH OBJECTIVE OF THE YERKES OBSERVATORY

By PHILIP FOX

Shortly after publishing[1] his method for testing objectives, Professor Hartmann directed a letter to Professor Hale, reviewing briefly the results of his investigations on the Potsdam objectives and on the 27-inch Grubb and 12-inch Clark objectives in Vienna, and speaking of the interest that would be felt in an investigation of the 40-inch objective. He concluded by saying, "Ich würde gern bereit sein, die nöthigen Messungen und Rechnungen auszuführen, wenn Sie mir nur zwei photographische Aufnahmen mit dem 40-inch Refractor anfertigen lassen wollten."

In compliance with this request, the extra-focal exposures were made by Professor Barnard on February 1, 1902. Professor Hartmann communicated the results of his measurements to Mr. Hale in April of the same year. Positives from these plates have been measured also by Mr. Ichinohe, recently fellow at this observatory, who further measured a pair of plates exposed by Mr. Jordan in April of 1906. In the table on the following page will be found the results of the measurements of the early plates. The agreement is fairly close.

In discussing the results Hartmann wrote: "So viel man aus diesen wenigen Punkten erkennen kann, ist das Objectiv ganz vorzüglich. Von $r=26$ cm bis zum Rande besteht nur eine Focusdifferenz von

[1] *Astrophysical Journal*, 12, 46, 1900.

0.05 in.; ich habe eine so kleine Differenz noch bei keinem anderen Objectiv gefunden. Dass die Mitte des Objectivs etwas kürzere Brennweite hat, ist bei der geringeren Apertur der betreffenden Strahlenkegel unschädlich. Uebrigens würde sich dieser Fehler durch nochmaliges Nachpoliren der Mitte, so dass das Objectiv dort etwas flacher würde, leicht beseitigen lassen."

Radius of Zone	Focal Scale Readings	
	Hartmann	Ichinohe
mm	Inches	Inches
100	8.860	8.877
140	8.911	8.939
260	9.016	9.010
300	9.047	9.048
420	9.060	9.096
460	9.023	9.039
490	9.022	9.025

Hartmann, however, considered the investigation incomplete because so few zones were included. It is evident that undetected irregularities might lie in the gap between $r=300$ and $r=420$. The writer had the pleasure of working with Professor Hartmann in Potsdam for a few weeks in 1906, and measured some of the plates made in the tests of the 80-cm Potsdam refractor. At that time Hartmann urged the need of a more thorough test of the 40-inch objective. This investigation was therefore inaugurated.

90°

0°

FIG. 1.—Extra-focal Star Images for the Zonal Investigation.

The method first published in this *Journal* (*loc. cit.*) was later more fully developed in the *Zeitschrift für Instrumentenkunde* (**24**, 1, 33, 97, 1904). As it has recently been referred to somewhat in detail in this *Journal* by Plaskett,[1]

[1] *Astrophysical Journal,* **25**, 195, 1907; also *Journal of the Royal Astronomical Society of Canada,* **1**, 104, 297, 1907.

TABLE I

ZONAL FOCI

Radius of Zone	ϕ	Objective Alone							Objective with Correcting Lens	
		1	2	3	4	5	5 (S)	Mean	6	7
mm		mm	mm	mm	mm	mm	mm	mm	mm	mm
490	15°, 105	210.23	210.04	206.11	211.40	211.39	210.92	209.83	262.64	265.22
480	75, 165	207.84	207.98	204.20	209.93	209.40	209.41	207.87	261.18	264.11
460	45, 135	206.92	207.63	204.36	210.04	209.65	209.74	207.72	262.48	264.09
440	60, 150	207.74	207.32	204.73	210.58	210.66	210.42	208.21	263.39	264.82
420	30, 120	207.40	207.54	205.03	211.04	211.02	211.10	208.41	263.33	264.93
400	0, 90	206.92	206.76	204.50	210.48	210.64	210.68	207.86	262.83	264.24
370	15, 105	206.37	206.76	204.21	210.38	210.81	210.78	207.71	262.06	264.40
340	67.5, 157.5	206.05	205.29	203.41	209.73	210.25	210.57	206.95	261.36	263.07
310	45, 135	204.61	205.37	202.48	209.71	209.63	209.92	206.36	260.09	262.51
280	0, 90	205.69	205.46	203.16	210.33	209.98	210.10	206.92	259.96	262.39
250	22.5, 112.5	206.11	205.88	203.30	209.55	210.78	211.02	207.12	260.16	262.12
230	60, 150	205.03	205.54	203.04	210.59	210.40	209.92	206.92	259.40	261.37
170	0, 90	201.67	202.24	199.77	205.73	206.38	206.64	203.16	255.42	257.82
140	45, 135	203.21	204.01	201.07	209.57	208.94	208.39	205.36	257.19	259.00
70	0, 90	201.53	200.66	198.50	203.09	202.66*	201.08*	201.29	254.31	255.63

*Poor images.

in his thorough investigation of the 15-inch objective of the Dominion Observatory, I shall not review it here. The perforated diaphragm for the present zonal test had sixty holes located at the corners of squares on fifteen different zones. The arrangement can be well seen in Fig. 1, which is a reproduction of one of the plates measured. The holes were two centimeters in diameter. Of the several pairs of exposures made, five were suitable for measurement and enter in the discussion. Also two pairs were made with the photographic correcting lens of the Bruce spectrograph in position.

During the exposures the telescope was carefully guided by means of the long-focus finder ($f=62$ ft.). When necessary the telescope was moved with the slow-motion motors. The images show no appreciable guiding errors.

The results obtained from the measurement and reduction of the plates are given in Table I. The first column gives the radius of the zones; the second gives the position angles of the holes in the diaphragm, which are measured counter-clockwise with 0° on the edge of objective away from the pier. Columns headed 1, 2, 3, 4, and 5 give the focal scale readings in millimeters for the five pairs of plates. Column 5 (*S*) gives results obtained from plate 5 by Professor Slocum of Brown University, volunteer research assistant at this observatory in the summer of 1907. The excellent agreement of the two sets of measurements on plate 5 speak well for the accuracy of the method. As the plates were exposed at different temperatures, there is considerable variation among the different plates. The mean values of column 9 do not include results in column 5 (*S*). The results are shown graphically in Fig. 2. Small values of the focal setting indicate short focal length. I have not drawn a curve for Slocum's results but have indicated them with circles.

It is at once apparent that the center of the objective is of appreciably shorter focal length than the edge, confirming the earlier extra-focal investigations. It is further seen that certain of the curves show gradual shortening of the focus with approach toward the center, while others, Nos. 4 and 5, show but little shortening until the zone $r=210$ mm is reached.

It is interesting to see what effect the variations in form of the curve has on the image. Hartmann has introduced a criterion "*T*," for

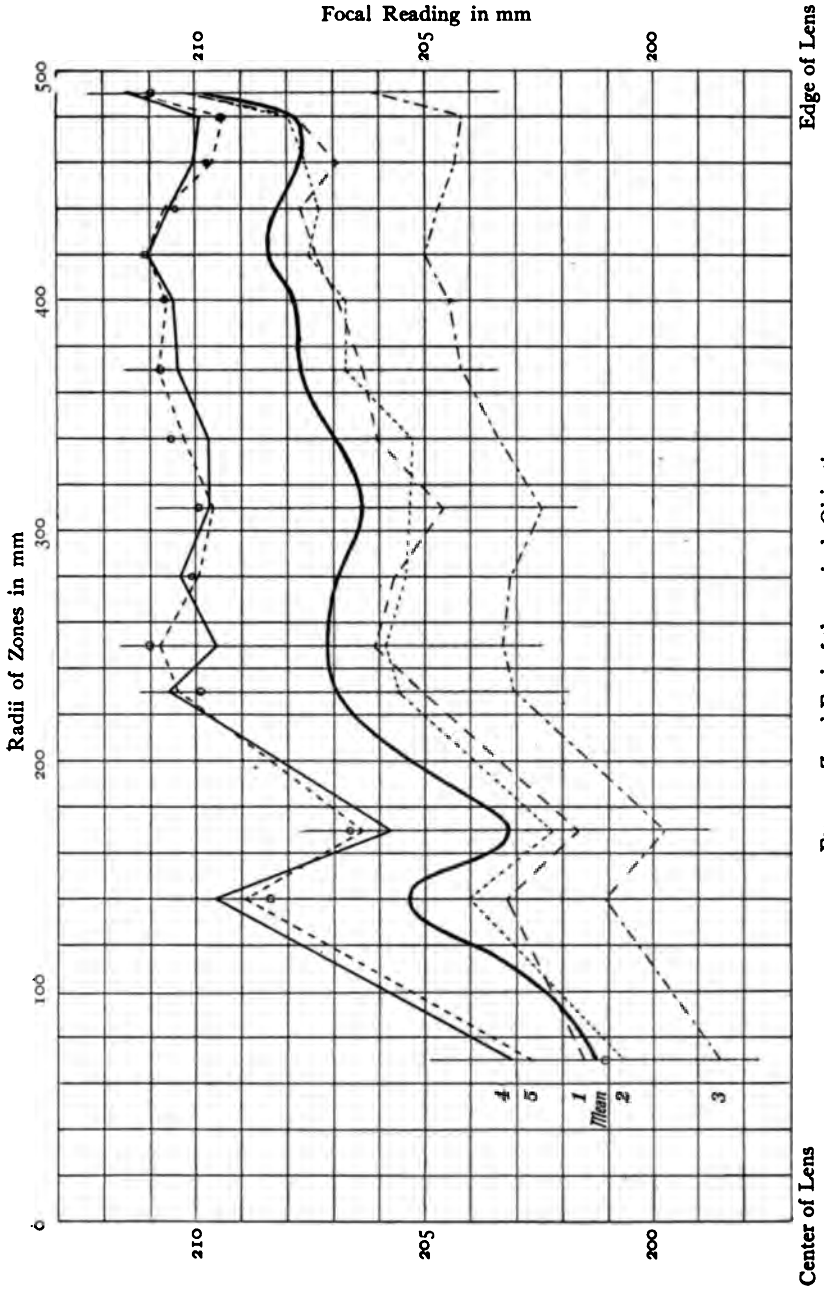


FIG. 2.—Zonal Foci of the 40-inch Objective

comparing objectives, defined as the weighted mean diameter, expressed in hundred-thousandths of the focal length, of the cones of light from the various zones in that plane, F_0, where the circle of light containing all of the converging pencils is smallest. Weights are given according to the light-gathering power of the zones, that is, according to their radii, r.

$$T=\frac{100{,}000}{F_m}\frac{\Sigma rd}{\Sigma r}=\frac{200{,}000}{F_m{}^2}\frac{\Sigma r^2(F-F_0)}{\Sigma r}.$$

Hartmann states that after locating the plane F_0 we might use the diameter of this smallest circle containing all the light, that is, the maximum of d, as a criterion of the quality of the objective; but it would be more nearly correct to take the mean value of d, for it is

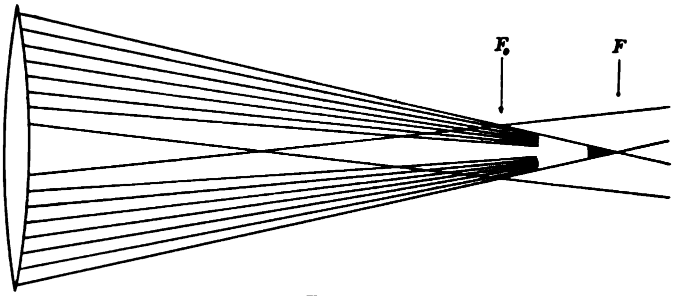


FIG. 3

possible that the maximum of d might depend on a small zone weak in light-gathering power. But this, too, while surely giving a better test, might give results poorly indicating the quality of the objective. I have shown such a case (of course very greatly exaggerated) in Fig. 3, where all the zones except one near the center give a common focus. It is evident that in practical work with such an objective the focus used would be at F (and not at F_0), and it would be manifestly unfair to judge it by even the mean diameter of the cones in the plane F_0. To free F_0 from its dependence on any one zone I have sought that plane for F_0 where the mean weighted diameter of the converging cones, Σrd, is a minimum. I had thought that this plane might be determined by taking the mean of the several foci, weighting them according to the angle of the cone and according to the light-gathering power; that is, roughly

$$F_0=\frac{\Sigma r^2F}{\Sigma r^2}.$$

TABLE II

CRITERION T

Plate Number	F_0 Hartmann	$F_0 - \frac{\Sigma r^2 d}{\Sigma r^2}$	Σrd = Minimum	T Hartmann	$F_0 - \frac{\Sigma r^2 d}{\Sigma r^2}$	Σrd = Minimum	Zenith Distance	Temperature	Star	1907
1..........	208.03	207.12	207.12	0.298	0.239	0.239	35°	− 1.°0 C	*Arcturus*	Feb. 9
2..........	208.03	207.18	207.30	0.276	0.233	0.229	53	− 1.0	*Vega*	Feb. 9
3..........	204.48	204.27	204.27	0.162	0.160	0.160	31	− 6.0	*Pollux*	March 3
4..........	209.94	210.31	210.31	0.125	0.109	0.109	14	+12.2	*Vega*	June 8
5..........	210.10	210.30	210.60	0.145	0.136	0.130	9	+20.0	*Vega*	June 15
5 (*S*).......	209.69	210.26	210.50	0.162	0.123	0.117	9	+20.0	*Vega*	June 15
6..........	261.16			0.264			25	+ 4.0	*Arcturus*	March 16
7..........	263.31			0.254			25	+19 5	*Vega*	June 15

One or two trials for F_0 on either side of this plane advancing in steps of 0.1 mm will give the plane where Σrd is a minimum. Table II gives F_0 according to Hartmann's formula, $F_0 = \frac{\Sigma r^2 F}{\Sigma r^2}$, and F_0 where Σrd = a minimum, also T for these three different values of F_0. In computign T I have taken Barnard's value, 19,354 mm, for the focal length F_m. I have added columns giving the star's name, the date of exposure, the zenith distance at the middle of the exposure, and the temperature. I should remark that the two exposures on plate 1 were separated by $1^h 32^m$, so that here the zenith distance is a mean of 41°5 and 28°.

Hartmann classes an objective as, "pre-eminently good," when T is less than 0.5; here all of the different pairs of images give values well within this class, although there is a considerable range in the values. Plates 4 and 5 are especially good. I have compared the values of T, having regard to the zenith distances, to see if the variation could be explained by flexure of the objective, and find that the performance seems to vary with the zenith distance, the object-glass giving better results when it lies horizontally. A more thorough investigation would be necessary to settle this point definitely. A series of plates on a star transiting near the zenith, say *Capella*, following the star from the zenith to the horizon should decide the question. Should this indicated relation be confirmed, it would seem that even if mechanical difficulties could be lightly overcome, refractors cannot be constructed of notably greater dimensions than the 40-inch with the hope of uniform performance at all altitudes.

With the spectrographic correcting lens in position, I found the same type of curve of zonal errors, although the curves are somewhat steeper. The focal settings are given in Table I, in columns headed 6 and 7, and are shown graphically in Fig. 4. The values of T given in Table II are not greatly different from those of the objective alone, and put the combination in the class "excellent."

With the holes in the diaphragm in a square configuration for each zone, the focal length may be determined in two planes perpendicular to each other, and any difference in the two will be due to astigmatism, if we disregard the disturbing effect of possible local errors. In Table I, I have given only the mean of the focal lengths in the two planes; this, subtracted from the two individual determinations, gives

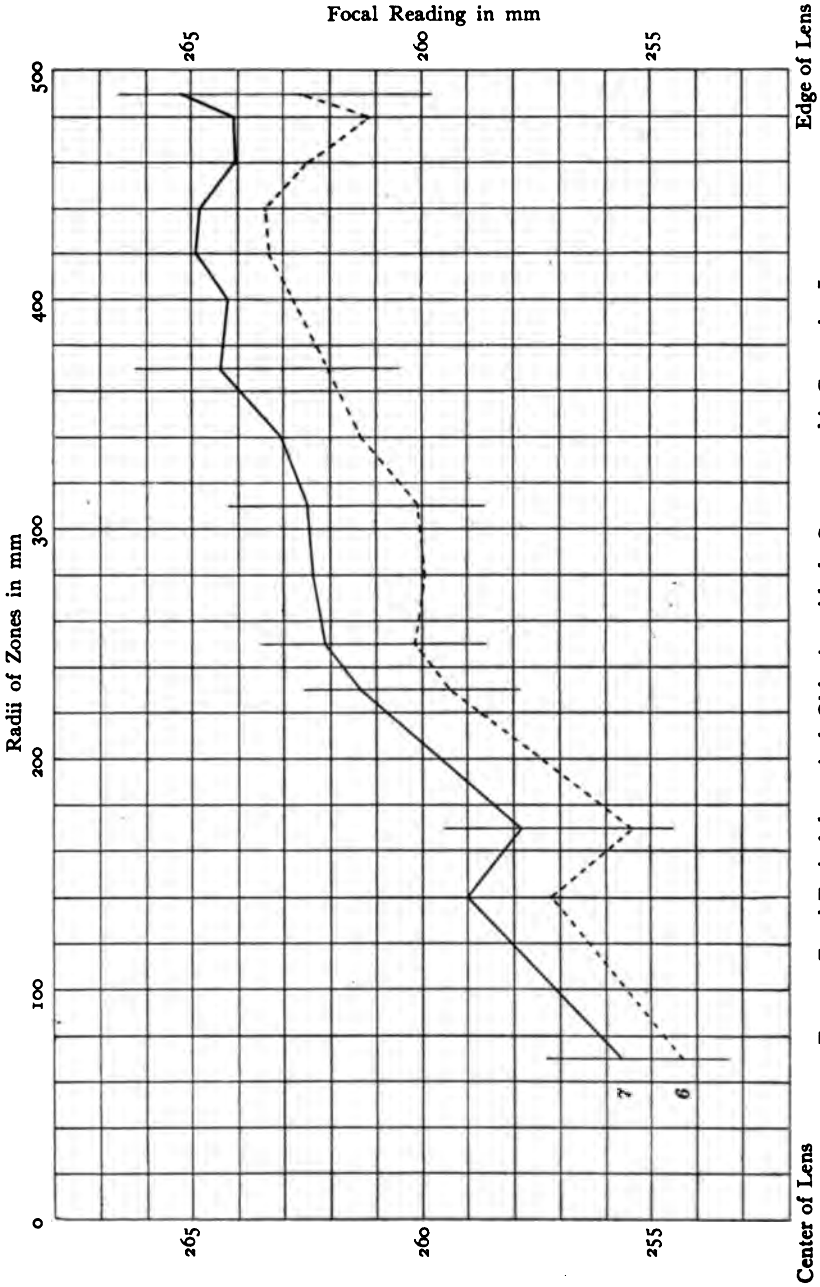


FIG. 4.—Zonal Foci of the 40-inch Objective with the Spectrographic Correcting Lens

the astigmatic errors presented in Table III. Errors for $\phi + 180°$ are identical with those for ϕ, those for $\phi + 90°$ and $\phi + 270°$ have the opposite sign. These errors are shown graphically in Fig. 5. The negative values, those shorter than the mean for the zone, are

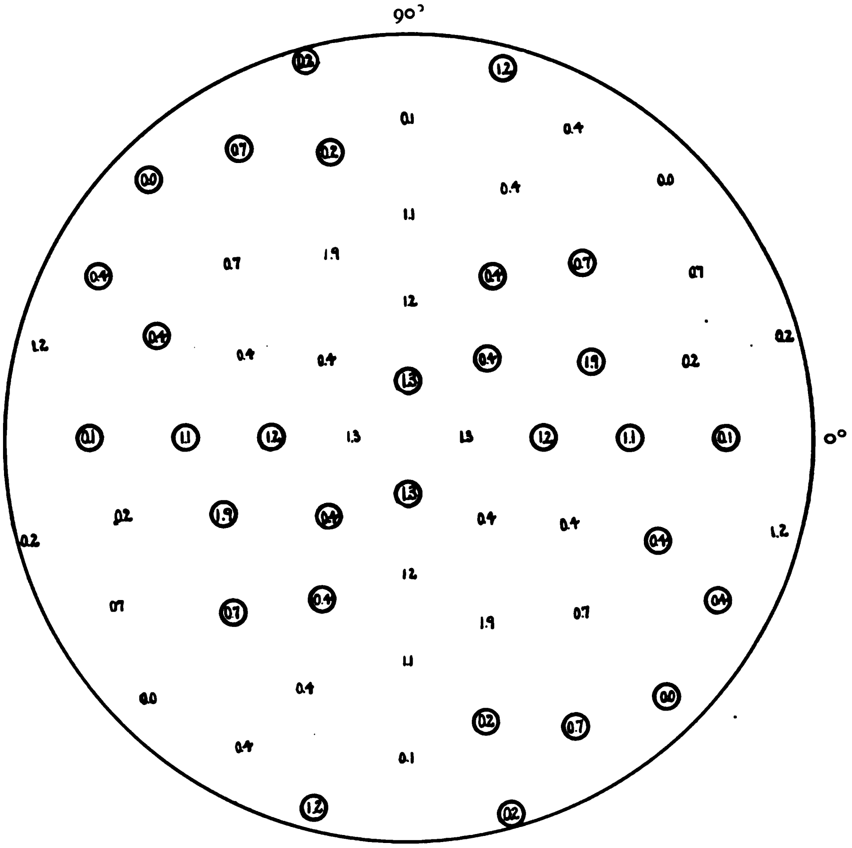


FIG. 5.—Astigmatic Errors of the 40-inch Objective

inclosed in circles. A glance reveals the distribution of the deficient and excessive values. Considering the objective as a whole, there is no well-defined figure showing the direction of the axes of the feeble astigmatism present. The only figure traceable is a double letter S, crossed after the fashion of a swastika. Within a radius of 30 cm from the center the axes are more clearly marked. The errors of this kind are all small, only five zones giving errors in the mean values

TABLE III

ASTIGMATIC ERRORS

Radius of Zone	ϕ	Objective Alone							With Correcting Lens	
		1	2	3	4	5	5 (S)	Mean	6	7
mm		mm	mm	mm	mm	mm	mm	mm	mm	mm
490	15°	+0.24	+0.55	+0.34	+0.10	−0.32	−0.13	+0.18	+1.71	+0.69
480	75	−1.30	−1.79	−1.23	−1.12	−0.76	−0.91	−1.24	+2.29*	−1.24
460	45	−0.49	+0.02	+0.42	−0.01	+0.18	+0.52	+0.02	+0.50	+1.07
440	60	+0.20	+0.09	+0.69	+0.35	+0.70	+0.55	+0.41	+0.27	+0.86
420	30	+0.68	+0.74	+0.96	+0.48	+0.72	+0.59	+0.72	+1.91	+1.47
400	0	+0.13	+0.10	−0.08	−0.15	−0.72	−0.88	−0.14	+1.06	−0.06
370	15	+0.33	+0.53	+0.52	−0.11	−0.29	−0.42	+0.20	+1.53	+0.61
340	67.5	+0.18	+0.28	+0.45	+0.31	+0.82	+0.65	+0.41	+0.12	+0.33
310	45	−1.00	−0.86	−0.59	−0.98	−0.28	−0.01	−0.74	−0.16	−0.23
280	0	−1.24	−0.89	−1.21	−0.78	−1.29	−1.46	−1.08	+0.03	−0.54
250	22.5	−2.03	−1.86	−1.68	−1.81	−2.12	−2.67	−1.90	−0.58	−0.66
230	60	−0.73	−0.28	−0.33	−0.06	−0.54	−0.54	−0.39	−0.30	−0.17
170	0	−1.45	−2.11	−1.28	−0.31	−0.60	−0.36	−1.15	+0.58	+0.35
140	45	−0.34	−0.65	−0.04	−0.05	−0.78	+0.58	−0.37	+0.41	−0.20
70	0	+0.48	+3.40	+0.72	−0.04	+2.16*	+6.44*	+1.34	−0.14	+1.52

* Poor images.

greater than 1 mm, and four of these are zones of small radii, weak in light-gathering power, and of small divergence.

With the correcting lens in position the astigmatic errors are of about the same magnitude as with the objective alone. They are given in Table III.

The tests described above have been confined to fifteen zones irregularly distributed on the objective, being somewhat crowded at the edge, and the result for each zone rests on but four points. Had I rotated the diaphragm, thereby obtaining additional material for each zone, it is probable that some of the smaller irregularities in the zonal focus-curves would have been eliminated, and T would have

A. Foucault. *B*. Foucault. *C*. Extra-focal.

FIG. 6.—"Focograms" of the 40-inch Objective

been somewhat reduced. The results obtained, however, probably represent the quality of the object-glass as well as a test depending upon a limited number of points can. It might be well to state here that under the best conditions the objective has separated double stars down to its theoretical resolving power.

In order to depict the 40-inch objective as a whole, I have again followed Hartmann, who has recently applied photographically the Foucault knife-edge test to the 80-cm objective at Potsdam, revealing an astonishing amount of detail in the surface, even traces of the epicycloidal motion of the polishing tool. (See the translation of his paper on page 254 of this number.)

I have made several exposures, principally on *Sirius*, introducing the knife-edge from different directions. Two of these images are reproduced in Fig. 6, *A* and *B*. These show the objective in $\frac{1}{40}$ its

natural size. The telescope was west of the pier and directed toward *Sirius*. In *A* the knife-edge was inserted from below, in *B* from the left, the pier side. The arbitrary position angles on the objective used in the zonal work are retained here.

No set of epicycloids is recognizable but there are some minute irregularities of curious form. Most noticeable is the stria crossing the objective in $\phi = 130°$. This, together with the stria at $\phi = 295°$, was seen in a visual knife-edge test. Aside from these striae, most conspicuous are the gap near the edge, corresponding to the depression in the zonal curve at $r = 470-480$ mm, and the quadrangular configuration near the center which may perhaps cause the larger astigmatic errors of the small zones. In *B* there are four dark spots caused by bits of frost on the object-glass. *A* was taken under much better conditions of seeing than *B* and consequently shows greater contrast. It is interesting to notice the difference in the illumination on certain irregularities in *A* and *B*, which depends on the direction of insertion of the knife-edge. Aside from the irregularities noted, the objective is very uniform.

The irregularities of surface or of density in the glass are perceived because they give variations from the mean focal plane of the objective. These variations should cause non-uniformity in the distribution of light in the extra-focal star image, and here the pattern should be similar to the irregularities of the objective. Photographs which I have made of the extra-focal star image, Fig. 6, *C*, confirm this. Practically all of the irregularities shown in *A* and *B* are traceable in *C*, although, naturally, there is not the sharpness shown in the knife-edge plates. *A* and *B* show the causes of the effects vaguely apparent in *C*.

COLOR-CURVE OF FORTY-INCH OBJECTIVE

A re-examination of the color-curve of the objective was a part of my programme, and for this purpose I assembled a small spectrograph and made tests by means of extra-focal star spectra. The screen before the objective, shown in Fig. 7, had apertures measuring 6×16 cm, on three different zones at radii $r = 170$, 310, and 450 mm. I am indebted to Mr. Wallace for the preparation of plates for the tests. They were bathed in an aqueous ammoniacal solution of pinacyanol + pinaverdol + homocol, as described in his recent paper on

"Orthochromatism by Bathing."[1] For this plate he has adopted the name "pan-iso." With them I obtained spectra measurable from H_α to H_ϵ when working outside of the focus. A pair of these spectra exposed on *Vega* is shown in Fig. 8. Three pairs of plates were measured to determine the color-curve of the objective alone. The results are given in Table IV. As the recorded temperatures for the three pairs of plates varied but slightly, the results are directly comparable. I have platted the mean results for the three plates in Fig. 9, where I have indicated data from plate 1 with circles, from plate 2 with dots, and from plate 3 with crosses. The influence of temperature is clearly indicated; the open circles are a mean between the dots and the crosses. This color-curve is practically identical with that by Ellerman[2] and with an unpublished curve by Frost determined by the older method of strictures in stellar spectra.

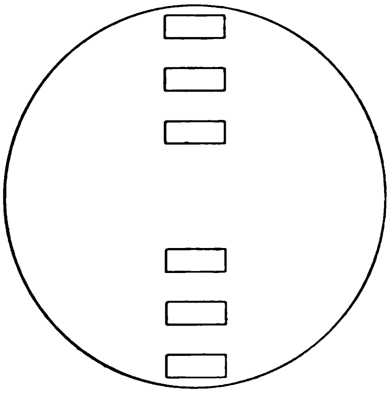


FIG. 7.—Diaphragm for Color-Curve Spectra.

As the color-curve was determined for three different zones, there is material for a meager test for zonal errors in monochromatic light. Zones $r = 450$ mm and $r = 310$ mm give results in close agreement. In the visual portion of the spectrum the latter gives results in excess of the former by a few tenths of a millimeter. This is contrary to the

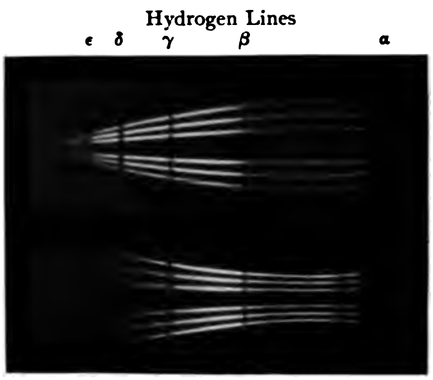


FIG. 8.—Spectra for the Determination of the Color-Curve (*Vega*).

[1] *Astrophysical Journal*, 26, 316, 1907.

[2] *Ibid.*, 10, 94, 1899.

TABLE IV

Color-Curve of Forty-Inch Objective

λ	1. *Arcturus.* Temp. = 21°6				2. *Vega.* Temp. = 20°				3. *Vega.* Temp. = 22°0			
	450	310	170	Mean	450	310	170	Mean	450	310	170	Mean
6800	462.41	462.81	459.66	461.63	......	......	......	......	......	......	......	......
6563	......	......	......	......	455.10	455.69	452.44	454.41	456.39	457.21	454.93	456.18
6270	451.25	451.87	448.85	450.66	......	......	......	......	......	......	......	......
5893	446.91	447.87	444.28	446.35	......	......	......	......	......	......	......	......
5800	......	......	......	......	......	......	......	......	447.17	447.53	445.62	446.77
5760	......	......	......	......	446.07	446.89	442.58	445.18	......	......	......	......
5732	446.14	446.63	443.06	445.28	......	......	......	......	......	......	......	......
5490	446.48	446.71	443.36	445.52	......	......	......	......	......	......	......	......
5283	448.36	448.69	444.95	447.33	......	......	......	......	......	......	......	......
5275	......	......	......	......	......	......	......	......	448.53	449.01	444.94	447.49
5240	......	......	......	......	447.83	448.89	444.20	446.97	......	......	......	......
5184	450.02	450.23	446.21	448.82	......	......	......	......	......	......	......	......
4862	459.18	459.08	455.37	457.88	459.03	458.96	453.08	457.02	460.30	459.96	456.13	458.80
4710	467.27	466.44	462.44	465.38	......	......	......	......	......	......	......	......
4580	......	......	......	......	476.29	475.40	470.12	473.94	......	......	......	......
4540	479.87	479.16	474.49	477.84	......	......	......	......	......	......	......	......
4383	493.38	494.09	488.29	491.92	......	......	......	......	......	......	......	......
4340	498.77	498.28	492.82	496.62	498.21	498.19	492.42	496.27	500.36	499.12	496.55	498.68
4308	503.30	502.49	498.55	501.45	......	......	......	......	......	......	......	......
4272	508.19	506.79	503.62	506.20	......	......	......	......	......	......	......	......
4227	514.31	514.00	507.78	512.03	......	......	......	......	......	......	......	......
4110	535.20	534.73	529.94	533.29	......	......	......	......	......	......	......	......
4102	536.65	534.52	530.29	533.82	536.42	536.26	529.51	534.06	537.93	536.78	531.66	535.46
3969	......	......	......	......	566.37	565.92	561.16	564.48	568.55	568.06	564.36	566.99

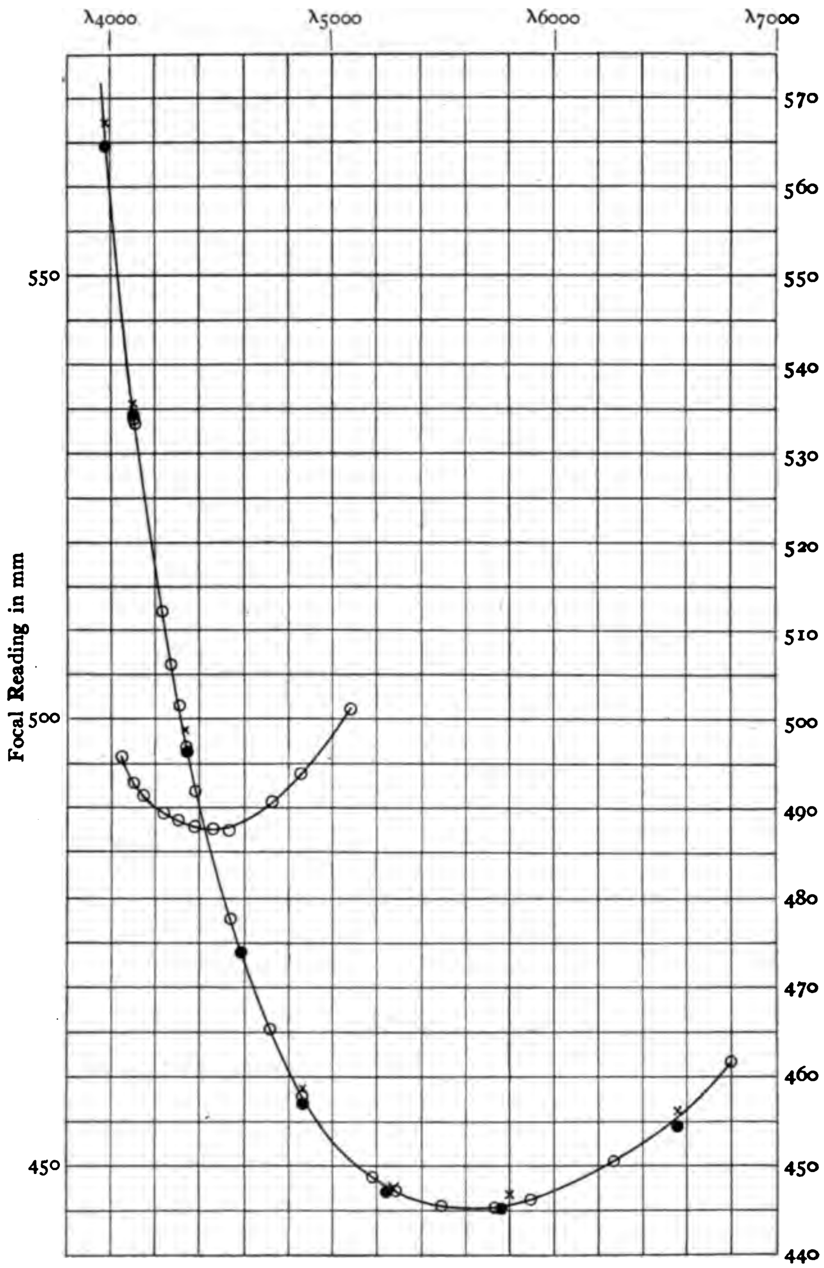


FIG. 9.—Color-Curve of the 40-inch Objective

results from the zonal investigation, where plates 4 and 5 give about 0.2 mm in the opposite direction. The quantities are small, however, so that this disagreement is not severe. Zone $r=170$ mm is between three and four millimeters shorter than the outer zones and this is in agreement with the zonal results. In the photographic regions the results from zone $r=450$ mm are larger than those for $r=310$ mm, and the differences between results for $r=450$ mm and $r=170$ mm have increased. In the red regions zone $r=450$ mm gives smaller readings than $r=310$ mm. These are the expected consequences of the chromatic difference of spherical aberration.

In Fig. 9 I have also platted the color-curve obtained with the spectrographic correcting lens in position using the mean values. The data are given in Table V. Zone $r=450$ mm gives longer focal lengths than $r=310$ mm by about 1.5 mm and longer than $r=170$ mm by about 9 mm, differences slightly greater than are shown in the zonal work.

TABLE V

COLOR-CURVE WITH CORRECTING LENS

λ	Focal Readings in Millimeters			
	450	310	170	Mean
5080	504.82	502.63	495.89	501.11
4861	497.53	495.89	488.08	493.83
4730	494.56	492.61	484.82	490.66
4535	491.41	489.39	481.48	487.43
4460	491.14	489.67	481.79	487.53
4383	491.19	489.74	481.88	487.60
4340	491.31	489.58	482.36	487.75
4308	491.76	490.41	483.17	488.45
4272	492.14	490.32	483.17	488.54
4227	492.99	491.10	483.61	489.23
4200	492.95	491.46	484.52	489.64
4140	494.34	493.23	486.38	491.32
4102	495.82	494.22	487.87	492.64
4046	499.15	497.47	490.81	495.81

I have presented somewhat in detail the results of the investigation of the 40-inch objective and I close by reiterating Professor Hartmann's wish that data might be published for every objective in active use.

I wish to express my indebtedness to Professor Frost for advice concerning the investigations; to Professor Slocum for measuring certain of the plates, and to Mr. Sullivan for assistance at the telescope.

YERKES OBSERVATORY
March 2, 1908

AN IMPROVEMENT OF THE FOUCAULT KNIFE-EDGE TEST IN THE INVESTIGATION OF TELESCOPE OBJECTIVES[1]

By J. HARTMANN

Until very recently matters were in an unsatisfactory state in regard to judging of the relative quality of the large objectives and mirrors used in astronomical observations, inasmuch as all data as to individual instruments rested for the most part on the subjective impressions of a few observers. A uniform measure of the quality of the different refractors and reflectors was wholly lacking. The method of extra-focal measurements[2] which I developed in 1899 first made possible a numerical determination of the so-called zonal errors and of the astigmatism, and this method has since then yielded a series of interesting conclusions as to different instruments. It has been used in several optical works for testing and perfecting their output, and has also served for correcting the principal error of the 80-cm objective of the astrophysical observatory at Potsdam. To recall it briefly, the procedure consists in isolating certain of the parallel rays from the cylinder of rays entering the objective, when it is pointed at a star, by a diaphragm perforated with holes and placed in front of the objective; the course of these rays is determined by obtaining the points of their intersection with two parallel planes.

In continuing the application of this method to the investigation of objectives as well as of complete spectroscopic apparatus, I frequently noticed that closely adjacent points of an optical system often indicated a quite decidedly different path of the rays, whence it was necessary to conclude that these systems occasionally fail to produce as regular a refraction as is ordinarily assumed. In addition to the extra-focal method, which gives the course of the rays for any desired points on an objective, though necessarily limited in number, it seemed to me desirable to have a second method of testing which

[1] Translated from *Sitzungsberichte der K. Preussischen Akademie der Wissenschaften*, Session of December 19, 1907.

[2] *Zeitschrift für Instrumentenkunde*, **20**, 51, 1900; **24**, 3, 1904.

should furnish a general view of the optical uniformity of the whole cylinder of rays transmitted by the objective, and thus permit the immediate recognition of the different parts of the optical system which cause an incorrect refraction.

It was clear to me from the start that such a process for testing could be obtained by a suitable application of the well-known "Schlieren" method proposed by Toepler in 1864; or better, by the method introduced six years earlier by Foucault, which is a special case of the Toepler experiment. In the so-called Foucault knife-edge test, the knife-edge is moved in from one side of the focal image of a terrestrial point-source, and the eye, placed close behind the focus, observes directly how the rays are thus cut off. If the objective is free from error, and therefore unites all of the rays coming from the source into a point image, then the eye held at a slight distance behind this image beholds the whole surface of the objective illuminated uniformly, and this light disappears uniformly over the whole surface as soon as the point image is concealed by the knife. But if there are some places in the objective of different refraction, the rays coming from these places will either be cut off before the principal image is concealed by the knife, and they will therefore appear as dark places on the luminous surface of the objective; or this irregularly refracted beam will not be cut off until after the principal image is concealed, and in this case the portions of the objective in question will betray their presence as bright spots on the surface of the objective already darkened by the knife.

This method of Foucault has been introduced in many optical works, and constitutes the principal means for the more accurate testing of objectives and mirrors. The method has, however, hitherto never been employed for testing on the sky an already mounted astronomical refractor; probably for the reason that various difficulties arise in its application.

These difficulties consist, on the one hand, in the impossibility of using a monochromatic source of light in observations on the sky, and, on the other hand, in the constant motion of the image due to the unsteadiness of the air. These two causes make it impossible to obtain a sharp occultation of a point focal image in the astronomical application of Foucault's method. It is nevertheless possible, as I

have found, to perceive in this way at least the larger zonal errors of an objective and this without further apparatus. It is sufficient for this purpose to place a strip of paper having a sharp edge, or a piece of tinfoil, over the opening of the adapter after the eyepiece has been removed, and then to move the paper so that its edge falls in the plane of the image, and thereafter to bring the image of a bright star on the edge by means of the slow motions. As long as this image is not reached by the edge, an eye close to the edge will see the whole objective uniformly bright in the cone of rays. But if the cone of rays is partly cut off by the edge, then brighter and darker places will appear on the objective, which give it a peculiar appearance as if seen in relief. The figure is intended to represent schematically an

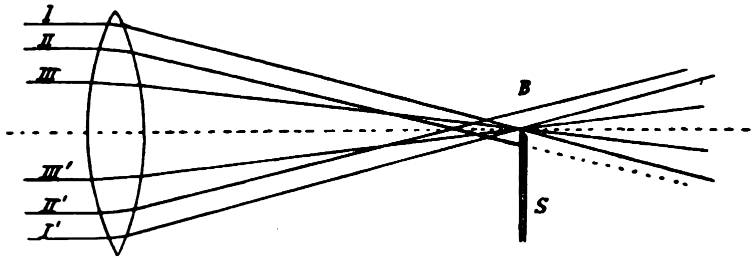


FIG. 1

objective, the greater portion of the surface of which unites in the focus B, the rays passing through the outer zone I as well as the central portion III, while there lies between these a zone II of shorter focal length. If the knife-edge S, which is brought up to the point B from below, has not quite reached this, then only the ray II of those shown in the figure will be cut off, and the eye will therefore see the surface II, which is of too short focus, as dark on a bright background on the side of the objective away from the knife-edge. If the knife-edge is moved farther on, so that it catches the rays passing through the point B, then only the ray II′, which similarly comes from the zone of too short focus, reaches the eye of the observer. This zone will therefore appear bright on a dark ground on the side of the objective toward the knife (lower side in the figure). It follows from this that such a zone of too short focus presents exactly the same appearance which would be given by the slope toward the edge of the objective (hence outward) of an annular elevation on the ob-

jective, if this was given a very oblique illumination from the side from which the knife-edge was brought up. A similar consideration shows that a zone of too great focal length will be represented as the inner slope of an annular ridge, or as the slope, facing the center of the objective, of a depression.

In the experiments I made in this manner on the 80-cm objective of the Potsdam refractor, I could recognize an apparent crater in diameter about equal to one-third of the diameter of the objective, and this fully confirmed what I had previously determined numerically by the extra-focal measures: the objective had in the zone $r=12$ cm a focal length too short by about 2 mm, but farther in, at $r=8$ cm, a too great focal length. A closer observation of the figure of the objective was hindered by the difficulties above mentioned, the image being very strongly colored by the secondary spectrum and very variable on account of the unsteadiness of the air. However, since there appeared to be further fine details on the surface of the objective which could not be determined with certainty on account of the continuous motion, the idea occurred to me of overcoming the difficulties mentioned by replacing the eye by a camera, the objective of which should throw upon the photographic plate a sharp image of the objective to be investigated. The motion of the stellar image was thus rendered entirely harmless, causing only a variable intensity in the illumination of the separate parts of the image, and thus contributing to a uniform effect in the formation of the image of the whole surface of the objective. The error due to color loses its disturbing effect because the photographic plate is not sensitive for the red and yellow rays, while the photographically active rays of shorter wave-length are well united by the objective. The knife-edge was in this case attached closely in front of the objective of the camera screwed on to the adapter at the eyepiece of the refractor. I will designate these pictures, in which the structure of the focus is photographically recorded, as "focographic" plates.

The result of my plates made in this way was quite astonishing. They showed a wealth of detail in the figure of the objective which was previously entirely unknown. This is shown in the reproduction of one of these "focograms" better than in words. Fig. 2 is the photographic image of the 80-cm objective in one-tenth its natural

size. We first recognize the ring lying at the middle of the lens, which gives to the picture a resemblance to one of the craters of the moon when illuminated from the left. This circular wall is the image of the above-mentioned zonal error. Next we recognize on the whole surface a sort of network of circles crossing each other, doubtless to be regarded as an effect of the epicyclic motion of the polishing tool. The brighter and darker spots that are irregularly distributed would probably be caused by slight irregularities in the

FIG. 2

mass of the glass. This is particularly true of the numerous thread-like streaks which are seen in the right-hand lower half of the picture; these are the so-called waves or threads in the substance of the glass. Finally the few bubbles and small "stones" are also represented as sharply defined white points. We can readily see that the threads and bubbles exert no disturbing effect on the density of the glass in their neighborhood, so that they do not injure the quality of the image.

I would here remark particularly that the 80-cm objective, while not indeed perfect, is still very good and gives quite sharp images.

If the optician should so figure it that all the irregularities here represented should be decidedly reduced, a process rendered much easier by these "focograms," then without doubt the highest perfection possible for this instrument would be reached. I will further add that investigations which I have made on other objectives have shown other phenomena which are in general similar. This focographic procedure is admirably adapted for the investigation of a spectrograph, since it instantly gives a clear picture of the effectiveness of the whole optical system. I shall report on this more thoroughly in another place.

POTSDAM

THE SPECTRUM NEAR THE POLES OF AN IRON ARC

By W. GEOFFREY DUFFIELD

Liveing and Dewar[1] in 1888 chronicled the occurrence of spark lines in the arc spectrum of magnesium. In 1903 Hartmann and Eberhard[2] found similar lines for silicon, zinc, and cadmium, and in the same year Hartmann[3] published an account of their behavior in the magnesium arc. Barnes[4] has also worked on this subject, investigating the effect of dielectric density on the intensity of the magnesium line. The most recent publication is that of Fowler[5] who describes the appearance in the iron arc of lines which are strongest at the tips of the poles and diminish in intensity as they approach the center. Though visible upon both poles, they are stronger at the positive pole. Fowler investigated the region F to C and pointed out the identity of these lines with the enhanced lines of iron and with those lines that are weakened in sun-spots. Photographs showing the same phenomenon (Figs. 1 and 2, Plate XVIII) have also been obtained by the writer with the large 21½-ft. Rowland grating of the Physical Laboratory of the Manchester University, and in view of the application of this investigation to solar phenomena (the extension of the sun-spot spectrum into the ultra-violet having recently been accomplished at Kodaïkanal Solar Physics Observatory) and to the resolution of spectral lines into series, the lines presenting this appearance have been identified, and a list is given below for the region $\lambda = 2350$ to $\lambda = 3500$.

The photographs were obtained by focusing a vertical image of the iron arc upon the vertical slit of the spectroscope, the length of the arc being so adjusted that the tip of each pole was just included upon the slit. The spectrum employed was of the first order where the dispersion is 0.4 mm per Ångström unit, and where the astigmatism

[1] *Proc. Roy. Soc.*, 44, 241, 1888.

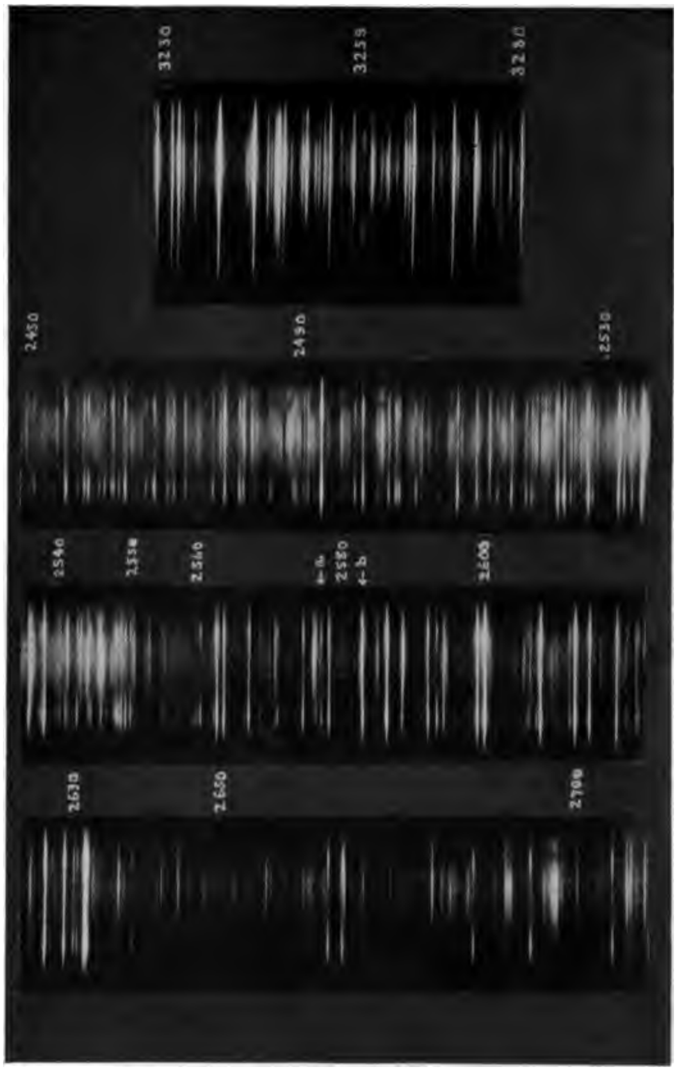
[2] *Astrophysical Journal*, 17, 229, 1903.

[3] *Ibid.*, 270, 1903.

[4] *Ibid.*, 21, 74, 1905.

[5] *Monthly Notices*, Royal Astronomical Society, 67, 154, 1907.

PLATE XVIII



1

a

2*b*

c

POLAR LINES IN THE IRON ARC

1. Pair of Polar Lines at λ 3259.
2. *a*. *b*. *c*. Polar Lines in the Ultra-violet Region.

is not sufficiently great to mask the phenomenon. The arc was at first fed from the city mains with continuous current, 40 volts being used across the terminals and 12 amperes being recorded by an ammeter in series with the arc.

The photographs obtained differ from those of Fowler in that the lines which appear most strongly at the tips are usually of the same intensity on the two poles. This is well shown by the pair at 3259 (Fig. 1), and by many lines in Fig. 2.

Identification of the lines.—For the region 2400 to 2550 Ångström units, direct measurements were made from the plates, the standards used being those lines for which there was good agreement between the measurements of Kayser and Runge for the arc and those of Exner and Haschek for the spark. For lines of wave-lengths less than $\lambda=2400$ and greater than $\lambda=2550$, Kayser's atlas of the iron arc spectrum was employed, but measurements were made whenever it seemed necessary.

Table I contains lists of the arc (K. and R.) and spark (E. and H.) lines whose wave-lengths approximate most closely to those of the lines appearing near the poles of the arc, together with measurements of the wave-lengths of the last-named when these were made. Estimates of the intensities of the lines in the three cases are also given, but as these were made by different observers they are not strictly comparable, and too much stress must not be laid upon their relative values. In the Table 1 is the smallest and 10 the greatest intensity.

A more valid comparison of the intensities of the lines appearing on the poles with those of the spark discharge has been made: a spark discharge was obtained by feeding the primary of an induction coil, whose hammer was clamped, with an alternating current (50 volts) and placing a Leyden jar in parallel with the spark-gap in the secondary. The usual form of comparison shutter was used and by its means a spectrum of the spark was compared with the spectrum given by the tips of the poles.

For the ultra-violet region $\lambda=2350$ to $\lambda=2631$ very little difference was found between the spark discharge and the arc spectrum, the lines of which were confined almost entirely to the neighborhood of the poles, the relative intensities of the lines being almost identical in this region in the two cases. But above $\lambda=2631$ a marked

difference between the two spectra makes its appearance, the lines of the arc being no longer mainly confined to the poles, but occurring, as in the characteristic arc spectrum, most strongly in the center of the arc. Nevertheless many lines still appear with greatest intensity on the tips of the poles and the comparison spectrum shows that in nearly all cases these correspond to lines in the spark, though not now with such close correspondence between their intensities: some few lines at the poles are without counterpart in the spark (e. g., 3076.54, 3078.79, 3132.10), and others which are sharp at the poles are fuzzy in the spark. On the other hand, to all lines occurring in the spark there are corresponding lines in the arc spectrum (with generally some small differences in their wave-lengths in the two cases) either at the center or at the poles of the arc. The conclusion reached is that both the wave-lengths of the lines occurring at the tips of the poles and their intensities point to their being more closely related to the spark than to the arc spectrum; but, since the relative intensities of the lines in the spark depend upon the capacity and self-inductance in the circuit,[1] too much stress is not placed upon the origin of the lines suggested in this way.

In view of these facts it is the writer's conviction that the term "spark" line is misleading when applied to lines which occur in what is to all intents a normal iron arc. More correctly they are lines which occur under conditions which may obtain both in the arc and in the electric spark, the property they have in common in the two cases being their most pronounced occurrence in the neighborhood of the poles. I suggest "polar lines" as a term less ambiguous than that of "spark lines." For those lines occurring most strongly in the center of either the arc or the spark, the term "median lines" seems suitable.

None of the ten photographs obtained in 1905 fails to show this phenomenon. It was suggested as a possible explanation of the appearance of these lines in the arc spectrum that a superinduced alternating current might have disturbed the continuous current supplied by the city mains, and have produced a weak spark discharge. The same effect was, however, obtained upon each of four additional exposures made when the current was taken from the storage batteries

[1] G. A. Hemsalech, *Journal de physique*, 9, 437, 1900; G. E. Hale, ***Astrophysical Journal***, 15, 132, 1902; W. B. Anderson, *ibid.*, 24, 221, 1906.

in the building. It should also be added that the exposure was not begun until the arc had been struck, and that it continued to burn steadily until the shutter was closed. In the photographs of the spark used for comparison the positive bands of nitrogen at $\lambda 3371$ and $\lambda 3158$ appear at the tips of the poles.

The effects of temperature, density, etc.—Various explanations have been proposed to account for the loss of luminosity of the polar lines as they proceed toward the center of the arc. Apart from the appearance of these lines, differences in the spectra[1] emitted by different parts of the arc have frequently been recorded and have been variously ascribed to differences in density, temperature, and potential gradient. Temperature does not seem able to explain the whole phenomenon, since the occurrence of these lines showing scarcely any difference in their intensity at the two poles (in many cases no difference is discernible) is not in accord with this hypothesis. Hartmann has found other grounds for rejecting it. Liveing and Dewar obtained the lines in the case of magnesium when the electrodes were surrounded by air, ammonia, steam, carbon dioxide, chlorine, and other gases, hence the inference is that the lines are not due to chemical interaction between the metal and the surrounding gas.

The cross-section of the arc is smallest in the neighborhood of the poles, hence it is natural to expect that a larger amount of light-energy will be admitted through the parallel jaws of a slit where the image of the poles falls upon it than where the center of the arc is focused. This may partly explain the decrease in the intensity of the lines as they approach the center on the supposition that the vapor producing them is homogeneously distributed throughout the arc, though it adds to the difficulty of explaining the characteristic formation of the arc or median lines in the center. Homogeneous distribution does not exist, however, and near the poles the greater velocity of the particles should effect a reduction in the number of particles present in unit volume and a consequent diminution of the photographic effect. The greater width of the lines near the poles may be effected by the greater velocity of the particles near them (if the arc and the spark are in this

[1] J. N. Lockyer, *Phil. Trans.*, **163**, 253, 1873; Thomas, *Comptes Rendus*, **119**, 728, 1894, etc.; H. Kayser, *Handbuch der Spectroscopie*, I, 165; H. Crew, *Astrophysical Journal*, **20**, 274, 1904

respect similar), which would render more obvious any line-of-sight motion they might possess after collisions.

The density and pressure are not determinate in an electric arc, and though it is doubtful whether either is constant throughout the arc, this condition is required to explain the fact that there is no observed curvature[1] of the spectral lines as they proceed from the poles toward the center of the arc. Differences frequently exist between the wave-lengths of lines occurring near the poles and those occurring in the center, and these discrepancies are illustrated by the pair at 2563 whose members are at the poles 0.95, and in the center 0.88 Ångström units apart (K. and R.), by the pair at 3259 which are at the poles 0.27, and in the center 0.65 Ångström units apart (K. and R.), and by the polar lines near 2490 which are on the violet edges of absorption lines in the center of the arc. The polar line marked *a* on the diagram at 2576.89 is a typical example of this, as it is on the edge of the line 2576.76 which appears only as a median line. The line marked *b* at 2582.62 is of a similar nature. Though the real correspondence of these lines is not established, the above evidence suggests a pressure or density displacement, but since the lines are invariable in wave-length for the ranges over which they occur, the influence of these physical conditions is doubtfully capable of explaining the displacements of the lines, though the increased width near the poles is quite possibly due to such cases.

On the other hand, the electrical conditions appear to determine the character of the explosion which takes place at the poles; upon the conditions of the disruption may depend the nature of the particle shot out and the type of vibration it possesses. According to Walter[2] who studied the "arc lines in spark spectra" the essential difference between the polar and median lines consists in the former being due to charged and the latter to uncharged particles—certainly the gradual appearance of lines in the center of the spark after the gradual disappearance of lines at the poles is suggestive of some action of this sort; a more radical change in the constitution of the particle is not out of the question.

Resolution of the lines into series.—The table which accompanies

[1] A difference in wave-length corresponding to a difference in pressure of two or three atmospheres should be capable of discovery.

[2] *Annalen der Physik*, 21, 223, 1906.

this paper will, it is hoped, assist in the resolution of the complex iron spectrum into series of lines; in it are included all lines observed with decreasing intensities as they proceed from the poles to the center of the arc. There is, however, a large range in their luminosity gradients, and a detailed study of these might further assist the resolution of the iron spectrum into series; but for this investigation photographic intensities are scarcely sufficiently reliable to justify the expenditure of the necessary time.

The median lines.—The character of the spectrum due to the center of the arc is of considerable interest; whereas the lines appearing near the poles are sharp and clearly defined, those in the center are very often diffuse and nebulous, this being specially noticeable where the polar lines are very numerous, e. g., in the extreme ultra-violet. Where they are less frequent the median lines are sharper, cf. the part of the spectrum near λ 3260 (Fig. 1). The nebulosity was thought at first to be due to a continuous spectrum produced by the poles of the arc, but the careful adjustment of the image of the arc on the slit precludes this explanation. It also sometimes happens that when a polar line occurs close to a median line, the polar line appears to gain in intensity at the expense of the median line. The pair at λ3259 affords an example of this; it is shown in Fig. 1 on the accompanying plate. The members of this pair of polar lines (intensity 4) are 0.30 Å. U. apart, and, though Kayser chronicles a pair of lines (intensity 1) in the normal arc about twice this distance apart (0.65 Å.U.), of which one line is identical with the red member of the polar pair, the violet member of the median pair (λ3258.50) is generally, though not invariably, much weakened when the polar lines are pronounced; it is absent from the photograph reproduced in Fig. 1. On other plates on which the polar pair is less strong, this violet median line is sometimes the strongest of the three. In Fig. 1 the absence of the median lines is possibly due to the energy of their vibration having been transferred to the particles producing the narrower pair near the poles.

The pair λ 2562.59, 2563.54 affords another and similar example of the above phenomenon, and the table includes more complete evidence of the changes in relative intensity between the median and polar lines.

I take this opportunity of expressing my gratitude to Professor Schuster for having placed the necessary apparatus at my disposal.

TABLE I
Polar Lines in the Arc Spectrum of Iron

Arc (K. and R.)	Arc Intensity*	Spark (E. and H.)	Spark Intensity*	Intensity at Poles*	S=Resembles Spark A=Resembles Arc Spectrum	Measurements of Polar Lines
2360.06	8	2360.08	5		S	In this part of the spectrum the intensities of the polar lines are difficult to estimate with the necessary accuracy. Direct comparison with a spark spectrum shows that the two are very similar
60.37	8	60.42	5		S	
64.88	10	64.90	7		S	
68.66	8	68.69	8		S	
75.30	8	75.30	6		S	
79.38	8	79.36	7		S	
80.82	6	80.86	5		S	
82.15	10	82.13	9		S	
83.24	8	83.17	2		S	
90.03	4	90.04	1		S	
95.62	10	95.73	7		S	
99.31	10	99.31	8		S	
2405.02	10	2404.98	7		S	
06.72	10	06.73	6		S	
10.56	10	10.59	8	6	S	10.62
11.16	10	11.15	7	6	S	(Standard)
13.37	10	13.36	8	6	S	
24.22	8	24.18	7	4		
30.16	6	30.18	7	4		
32.34	4	32.30	6	2	A	
32.97	2	32.92	6	1	A	
34.86	4	(34.70)	5	4	A	34.86
35.04	6	34.98	5	4		
39.36	6	39.35	6	6		
44.58	6	44.57	6	5		
45.68	4	45.67	4	4		
(49.93)	1	50.28	4	6	S	50.24
58.78	8	58.80	6	7		
61.28	8	61.36	5	6	S	61.35
61.89	4	61.90	5	5		
64.09	1	64.10	4	2		
66.02	2	66.00	4	1	A	
66.81	6	66.87	4	3	S	66.86
70.78	4	70.73	4	2	S	70.73
74.88	8	74.82	3	1	S	74.85
80.25	6	80.22	5	1		
81.11	1	81.11	3	5	S	81.12
82.16	4	82.18	4	5		(Standard)
.....		82.78	4	4	S	82.78
88.23	10	88.23	2	3	S	82.22
89.63	4	89.52	3	1		89.59
90.01	4	89.92	5	1†	A	90.04†
90.98	6	90.91	3	1†	A	91.04†
91.50	6	91.47	4	1†	A	91.52†
93.34	10	93.31	8	10		93.29
98.96	10	98.95	7	7		99.00
2502.53	8	2502.49	4	3	S	02.49
03.50	8	03.39	4	2	S	03.41

*Maximum Intensity = 10.

†Each of these three lines is on the red edge of an absorption line in the arc spectrum.

TABLE I—*Continued*

Arc (K. and R.)	Arc Intensity	Spark (E. and H.)	Spark Intensity	Intensity at Poles	S=Resembles Spark A=Resembles Arc Spectrum	Measurements of Polar Lines
(2503.89)	2	2503.97	5	3	S	03.98
06.98	6	07.11	1	4		07.06
11.84	4	11.85	7	7	S	(Standard)
(19.30)	4	19.14	5	5	S	19.15
25.48	6	25.50	7	7		
26.30	8	26.48	6	6		26.39
29.65	4	29.59	6	6	S	29.59
(33.86)	10	33.71	7	6	S	33.74
34.52	4	34.50	6	6		34.50
35.67	6	35.59	5	3	S	35.60
36.92	8	36.95	5	6		36.94
38.98 }	10	{ 38.95	5	8		38.94
..... }		{ 39.10	4	9	S	39.06
(40.90)	4	40.72	5	1	S	40.75
41.18	6	41.20	5	4		41.19
(42.20)	8	41.91	5	5	S	41.91
42.85	1	.....		2	A	42.80
43.47	4	43.49	5	7		43.45
(44.83)	8	45.05	3	2	S	45.04 ? *Cu*
(45.95)	2	45.32	3	4	S	45.30
(46.26)	8	46.80	5	4	S	46.75
(47.06)	8	47.43	4	3	S	47.41
(48.17)	2	48.42	3	1	S	48.37
48.76	6	48.73	3	2		48.78
.....		49.20	3	3	S	49.17
49.63	8	49.60	4	5		49.51
50.07	2	(50.20)	5	5	A	50.10
50.75	2	(50.87)	5	5	A	50.75
55.19	3	55.12	3	1	S	55.13
55.59	4	55.54	3	1	S	55.51
(57.42)	1	57.60	3	3	S	57.56
59.91	2	59.84	3	2*r*	A	59.91
60.43	4	60.39	4	4	S	60.36
(62.35)	4	62.16	3	2	S	62.16
62.63	10	62.59	6	8*	S	
63.51	10	63.54	5	8*	S	
66.99	8	67.01	4	7	A	
74.43	6	74.46	5	6		
76.20	6	76.18	1	3		Mn ?
(76.76)	8	76.89	5	4†	S	
78.01	10	77.98	5	7		
82.50	10*r*	82.62	7	8‡	S	
85.93	10	85.96	8	9		
88.11	10	88.05	5	4	S	

* At the poles the distance apart of these two lines is 0.95 Å. U. indicating that they approach the spark, rather than the arc.

† Marked *a* on photograph.

‡ This line (marked *b* on the photograph) is apparently reversed in the ordinary arc spectrum, but in this photograph is seen to be composed of two lines originating in different parts of the arc.

TABLE I—*Continued*

Arc (K. and R.)	Arc Intensity	Spark (E. and H.)	Spark Intensity	Intensity at Poles	S=Resembles Spark A=Resembles Arc Spectrum	Measurements of Polar Lines
2591.65	8	2591.65	6	7		
92.90	4	92.87	6	6		
93.75	6	93.80	4	6		
98.44	10	98.43	9	9		98.43
99.53	10	99.50	10r	10		
(2605.77)	8	2605.40	1	3	S	05.43
(06.92)	4	06.60	4	3	S	06.60
07.16	8	07.17	9	9		(Standard)
09.30	1	09.26	2	1		
11.16	2	11.16	3	3		
11.94	10	11.95	9	10		
13.91	8	13.91	9	9		
17.71	6	17.70	7	10		
21.72	8	21.78	6	6	S	21.77
25.72	10	25.67	5	8*	S	25.60*
.....		25.80	7	8*	S	25.78*
26.52	1	26.60	4	4	S	26.58
28.35	10	28.40	9	8r		28.39
29 66	1	29.67	5	5	S	(Standard)
30.13	2	30.16	3	5		30.15
31.07	10	31.14	4	7	S	31.13
31.37	10	31.46	4	7r		31.42
31.72	2	31.79	3	5	A	31.71
37.69	1	37.72	4	3		
39.60	1	39.66	3	2		
64.72	8	64.78	7	7		
66.72	4	66.75	7	7	S	
84.86	4	84.84	6	6		
92.71	4	92.68	6	6		
97.58	1	97.52	2	1		
2704.06	6	2704.10	5	6		04.07
07.13	1	07.23	3	1	S	07.21
09.13	2	09.14	3	3		(Standard)
11.92	2	11.94	4	5		11.92
12.42	2	12.48	2	2		
14.48	10	14.51	7	9		
16.31	4	16.30	4	5		
24.97	8	24.99	4	6		
27.61	8	27.59	8	7		
30.79	8	30.85	4	5		30.81
37.02	8	37.05	5	7		(Standard)
39.59	10	39.67	10	9		39.64
43.23	10	43.34	8	8	A	43.26
46.54	10	46.58	7	9		46.57
47.03	10	47.08	7	9		
49.42	6	49.40	10	10		
53.37	6	53.32	7	7		
55.77	10	55.82	10	10		55.82
61.83	8	61.88	3	6		

* Two lines occur on the poles, one in the arc and two in the spark.

TABLE I—*Continued*

Arc (K. and R.)	Arc Intensity	Spark (E. and H.)	Spark Intensity	Intensity at Poles	S—Resembles Spark A—Resembles Arc Spectrum	Measurements of Polar Lines
2767.56	10	2767.62	7r	8		
68.52	2	68.50	1	4		
68.98	4	69.03	3	4		
79.34	6	79.40	1	1	S	
83.75	8	83.81	7	6		
85.11	1	.....	..	3	A	
93.97	2	94.02	3	1		
99.34	1	99.42	2	1		
.....	..	2831.67	5	5	S	31.67
2835.76	2	35.82	4	1	A	35.74
39.66	1	.....	..	1	A	39.59
.....		39.85	2	1	S	39.87
40.73	2	40.82	3	1	A	40.72
48.13	2	48.15	2	3		48.11
49.67	1	49.70	2	2		49.65
55.75	2	55.77	3	1		
.....	..	2 faint pairs	..	2	S	
58.41	4	58.40	5	1		
71.16	1	71.19	2	1		
72.54	1	72.47	3	3		
73.48	2	73.49	4	2		
77.37	8	77.38	1	1	S	
80.84	6	80.89	3	5		
83.80	6	83.80	3	4		
.....	..	86.02	1	1	S	
.....	..	88.20	1	1	S	
.....	..	94.90	2	2	S	94.86
.....	..	95.35	2	2	S	95.27
97.33	1	97.37	2	1		97.34
2926.65	8	2926.71	3	6		
39.39	4	(39.62)	1	3	A	39.38
44.49	6	44.55	4	6	A	44.49
47.77	8	47.78	3	3		47.74
48.52	6	48.52	1	3		48.51
49.28	6	49.30	2	4	S	
64.30	2	64.25	1	1		
64.72	2	64.76	1	2		
65.14	4	65.17	2	3		
70.60	4	70.64	2	2		
79.44	1	79.48	1	2		79.47
(81.95)	6	82.20	1	1	S	82.18
84.92	8	84.97	6	7		84.95
85.65	6	85.70	4	6		
(97.51)	1	97.45	1	2	S	97.39
.....	..	3000.20	1	2	S	00.16
3002.74	4	02.80	3	5	A	02.75
(62.47)	1	62.33	2	1	S	62.33
76.60		.....		2	A	76.54*
77.32	1	77.30	2	2		

* No counterpart in spark comparison spectrum.

TABLE I—*Continued*

Arc (K. and R.)	Arc Intensity	Spark (E. and H.)	Spark Intensity	Intensity at Poles	S=Resembles Spark A=Resembles Arc Spectrum	Measurements of Polar Lines
(3078.50)		.....		2		78.79*
.....		.....		2		3132.10*
3154.29	1	3154.32	5	4	S	
77.64	1	77.64	3	4	S	
86.83	2	86.87	3	5		
3213.43	1	3213.45	5	1	A	
(58.50)	1	58.90	3	4†	S }	
59.15	1	59.20	3	4†	S }	
77.42	1	77.48	3	1		
3323.84	6	3323.83	2	1	S	
(3493.78)	2	3493.63	2	1		

* No counterpart in spark comparison spectrum.

† At the poles the distance apart of these two lines is 0.27 Å. U., indicating that they approach the case of the spark, rather than the arc discharge.

SUMMARY

1. In the arc spectrum of iron, some lines appear strong at the poles, diminishing gradually in intensity toward the center of the arc.

2. They have the general appearance of spark lines, but, to avoid ambiguity, the term "polar" lines is suggested to distinguish those lines occurring most strongly at the poles of the arc or the spark from those occurring most strongly in the center, for which term "median" lines seems suitable.

3. The polar lines are usually found with equal intensities on the two poles, but this is not invariably the case.

4. A list is given of the polar lines between λ 2350 and λ 3500 together with the intensities of the nearest "arc" and "spark" lines from the tables of Kayser and Runge and of Exner and Haschek.

5. Direct comparison with the spectrum from a spark discharge shows that between λ 2350 and λ 2630 all lines in the spark spectrum have their counterparts in the polar lines in the arc, and that the two spectra show a remarkable resemblance; but with increasing wave-length the arc becomes richer in median lines, some of which now correspond to lines from the spark discharge, and the polar lines decrease in number and intensity.

6. The numbers of polar lines in the arc are:

Between λ 2400 and λ 2500,	34	Between λ 3000 and λ 3100,	6
λ 2500 and λ 2600,	51	λ 3100 and λ 3200,	4
λ 2600 and λ 2700,	25	λ 3200 and λ 3300,	4
λ 2700 and λ 2800,	27	λ 3300 and λ 3400,	1
λ 2800 and λ 2900,	24	λ 3400 and λ 3500,	1
λ 2900 and λ 3000,	15		

7. The origin of the polar lines and the bearing of pressure, density, temperature, and potential gradient upon the phenomenon is discussed.

8. The distinctive character of the polar lines should assist in the resolution into series of the iron arc spectrum.

9. The median lines of the arc in the extreme ultra-violet are diffuse and nebulous, the polar lines sharp.

10. Instances are given of median lines losing in intensity in the arc when polar lines appear near them.

PHYSICAL LABORATORIES
MANCHESTER UNIVERSITY, ENGLAND
December 31, 1907

THE SPECTROSCOPIC BINARY ι *ORIONIS*

By J. S. PLASKETT and W. E. HARPER

This star (R. A. $5^h 30^m.5$; Decl. $-5° 59'$; Photog. Mag. 3.4), announced by Frost and Adams[1] as a spectroscopic binary, was placed under observation here for the determination of its orbit in December 1906. Of the 107 plates used for this purpose, 37 were made between December 11, 1906, and April 1907, with an adapted Brashear universal spectroscope, and the remaining 70 between September 14, 1907, and January 25, 1908, with the new single-prism Ottawa spectrograph. The linear dispersion of the Brashear instrument is 18.6 and of the single-prism spectrograph 30.2 tenth-meters per mm at $H\gamma$. Notwithstanding the greater dispersion of the former instrument more confidence should be placed, in the case of this star, in the results obtained by the latter, for two reasons. With the former instrument, owing to curvature of field of the camera lens, only two lines, *He*, λ 4471, and $H\gamma$, λ 4340, are accurately measurable; while with the latter all the lines, usually five or six from $H\beta$ to $H\epsilon$ inclusive, are available. In the second place, on the broad and diffuse lines of this spectrum, the settings can be more accurately made when photographed with the smaller dispersion.

The spectrum is of the helium type, the lines used for determining the velocity being given in the table below.

LINES IN SPECTRUM OF ι *Orionis*

Elements	Wave-Length
H	4861.527
He	4713.308
He	4471.676
He	4388.100
H	4340.634
H	4102.000
He	4026.352
H	3970.177
Ca	3933.825

The lines λ 4713, 4388, and 3933 are rarely measurable or even visible on the plates, and consequently they have been used only a few

[1] *Astrophysical Journal*, **18**, 386, 1903.

times. The other six lines have nearly always been used in the single-prism plates. Lines of wave-lengths λ 4686, 4543, 4143, and 4089 have been seen on some plates but never used in the velocity determinations. All the lines as stated above are very broad and diffuse, the widths varying between 2 and 4 tenth-meters. They are in many cases so faint as to be only with difficulty distinguished from the adjacent continuous spectrum. The difficulty of setting is further increased by the asymmetry of many of the lines; this asymmetry, combined with their diffuse character, rendering the settings uncertain. A peculiarity about this asymmetry is that all the lines of a spectrum are not necessarily affected in the same way. Some may have the maximum intensity to the red and some to the violet side of the band, while other lines may be nearly uniform. Although in one or two cases some of the lines appear doubled, this is by no means a common characteristic and this apparent doubling should not necessarily be assigned to the presence of a second spectrum, but possibly to some irregular arrangement of the silver grains in the naturally broad, diffuse, and asymmetric lines of the spectrum, or to some physical cause in the star's atmosphere. No evidence of the triple superposed maxima observed by Frost and Adams has been found on any of the plates, but this may possibly be due to the lower dispersion used here.

In consequence of the poor quality of the lines for measurement the radial velocities obtained may, in some cases, be in error to the extent of 15 or 20 km per second. Occasionally in two plates made on the same night there has been a difference of upward of 30 km in the measured velocity. That this difference is in great part due to the character of lines is shown by the fact that measures of the same plates by different observers occasionally differ about 20 km in the velocity. The probable error of a single plate, obtained by the use of the residuals from the final curve of oscillation, is for the Brashear spectroscope plates ± 7.8 km per second, and for the single-prism plates ± 6.6 km per second.

It is only when the range of velocity is large (in this case about 225 km) and where a large number of spectra have been secured, that a satisfactory orbit can be obtained for stars with this type of spectrum. The difficulty, in the present instance, is probably increased by the

high eccentricity of the orbit and consequently abruptly changing form of the velocity-curve, as well as by a probable secondary disturbance giving rise to a secondary curve superposed upon the primary.

The early observations with the Brashear spectroscope indicated a period of about 29 days. When use was made of Frost and Adams' observations of 1903 the period was approximately determined as 29.128 days. When all the observations were brought into one period it was at once seen that plates were required at the maximum and minimum points and along the rapidly descending branch of the curve, 3 or 4 days out of the 29. Cloudy skies at every recurrence of this epoch prevented these being secured during the winter of 1906–7, and it almost seemed that the same bad fortune was to prevail in 1907–8. Although partial success was obtained in October 1907, it was not until January 24 and 25, 1908, that the final observations necessary were secured. The observations of October indicated a period of 29.134 days, but the later plates changed this to 29.136 days. This can hardly be in error more than the thousandth of a day, as it is determined by the coincidence of an observation of Frost and Adams on September 5, 1903, with the rapidly descending branch as finally defined on January 25, 1908, 55 periods distant.

Originally each single measurement was plotted on cross-section paper, but as the number increased, plates taken on the same night (sometimes five in number at critical parts of the curve) were combined and their mean, weighted according to the quality of the plates, was used. When the period had been accurately determined those of nearly the same phase were grouped together and treated in the same way. In thus combining the observations there are only two groups (near apastron, where the change of velocity is slow) in which the difference of phase exceeds a day. The difference in the remainder is less than half a day and in most of these (all around periastron) less than a quarter of a day. This method of grouping prevents confusion and facilitates the drawing of the graph, while the effect of large accidental errors in the velocity values of some of the plates is diminished.

In addition to the 107 observations made at Ottawa, the 6 made at the Yerkes Observatory have been used and the 113 are combined into 27 groups with an average of somewhat over 4 observations each.

The phase, the mean velocity, and the number of measures in each phase are tabulated below.

Most of the measures on the Ottawa plates were made by Mr. Harper, while the grouping and discussion are due to Mr. Plaskett.

PHASES AND VELOCITIES

Phase	Mean Velocity	No. of Plates	Phase	Mean Velocity	No. of Plates
0.65.......	+101.3	5	14.53......	+ 27.4	5
0.82.......	+ 91.0	2	16.67......	+ 34.7	2
1.60.......	+ 30.8	10	18.44......	+ 34.3	4
1.85.......	− 21.3	2	19.32......	+ 41.2	2
2.43.......	−115.7	10	20.67......	+ 51.2	5
3.07.......	−118.2	5	21.55......	+ 45.3	3
3.44.......	− 92.1	5	22.65......	+ 57.	1
4.39.......	− 75.7	6	25.30......	+ 70.0	5
5.33.......	− 47.8	3	26.44......	+ 79.0	2
6.68.......	− 14.0	2	27.39......	+ 80.0	4
7.12.......	− 27.3	5	28.16......	+ 92.1	5
8.89.......	− 2.1	5	28.53......	+105.5	4
11.39.......	+ 15.0	4	28.93......	+104.9	5
13.05.......	+ 9.5	2			

These values are plotted in Fig. 1, where the full line is the velocity-curve corresponding to the elements $e=0.75$, $\omega=110°$, which were finally decided upon as the most probable.

Owing to the considerations previously mentioned, especially that relating to the possibility of a secondary disturbance, a final determination of the elements by the usual methods is out of the question. They only suffice to give preliminary values which must be corrected by a species of trial and error. For this purpose the method developed by Dr. W. F. King[1] has been found very useful as the labor of constructing an ephemeris and drawing the velocity-curve or of changing these to correspond to changes in the elements is reduced to a minimum. Less than half an hour suffices to draw the velocity-curve for any set of elements and consequently the trials of different values can be easily and quickly made.

No simple elliptic orbit will give a velocity-curve agreeing with a smooth curve drawn as closely as possible through the observed points; and we are forced to the conclusion that the differences are due either to errors in the observations or to secondary disturbances in the orbit. The latter seems to be the most likely, for although it is probable

[1] *Astrophysical Journal*, 27, 125, March 1908.

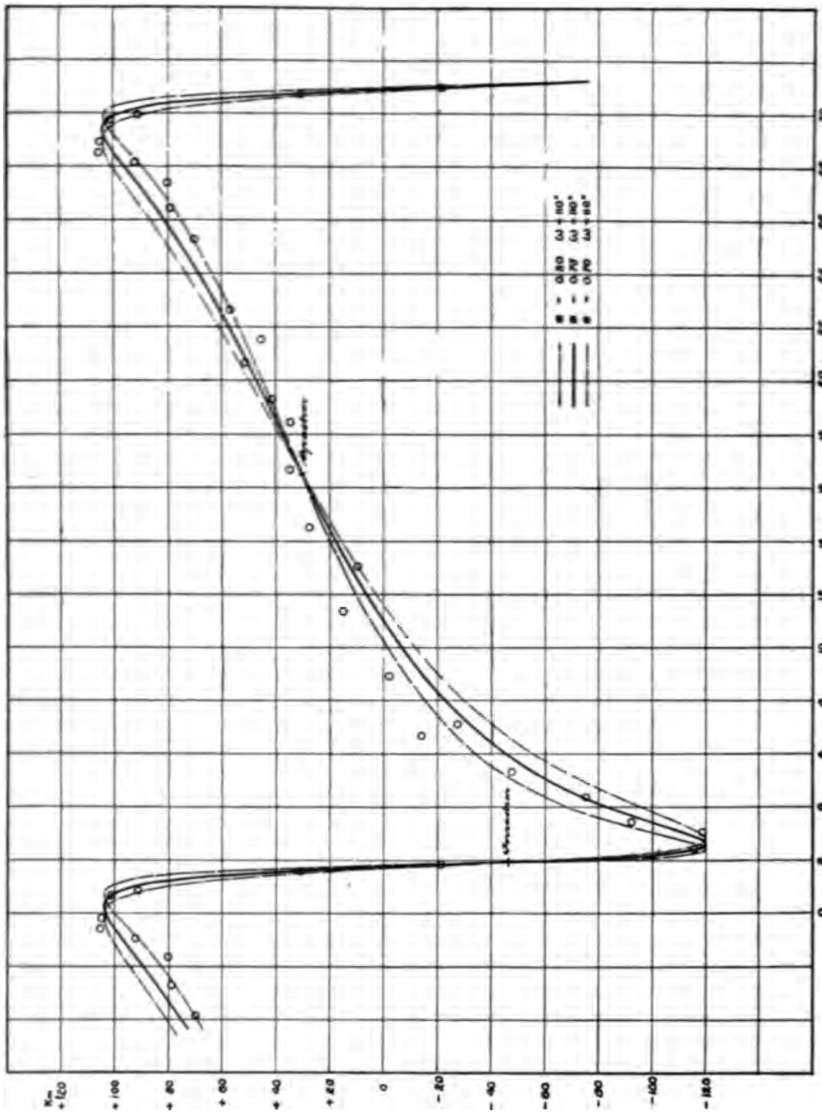


FIG. 1.—Velocity-Curve of ι *Orionis*

enough that two or three observations may be in error to the extent shown by the figure, it is hardly possible that for 10 or 12 days before apastron passage the residuals should be almost wholly negative and for 10 or 12 days after almost wholly positive.

These residuals can be considerably reduced and a curve agreeing fairly well with the observations on the ascending branch may be obtained by increasing the eccentricity to about 0.82. An eccentricity of 0.80 is shown by one of the dotted curves in Fig. 1. The use of an eccentricity of even 0.80 produces much higher residuals on the rapidly descending branch and at the points of maximum and minimum velocity, than an eccentricity of 0.75 in the ascending branch. In the descending branch any errors of observation or even any moderate secondary disturbance would have very little effect on the position or inclination of the curve. It was therefore considered preferable to determine the eccentricity by the inclination of the curve around periastron rather than by agreement around apastron, and it was for this purpose that observations in that phase were so long awaited. A reference to the curves of oscillation, Fig. 1, for $e = 0.70$, 0.75, and 0.80 shows that the eccentricity can be determined to within 0.01 by the inclination of the descending branch, and it may be stated that the same criterion may be used to determine the eccentricity, whatever the value of ω. Furthermore, the value of ω is also closely limited by the position of the curve near apastron. A difference of 1° either way would displace the curve too far up or down for the best agreement with the observations.

The above considerations led to the final choice of the elements $e = 0.75$, $\omega = 110^\circ$ as the most probable, while the question of a secondary curve is left open. The observations, even taking into account their high probable error, indicate the presence of such a curve but do not sufficiently define its position and amplitude to enable any explanation of its cause to be assigned. So far as known to the writer, previously discovered secondary disturbances have been submultiples of the main period, but such is apparently not the case here where the secondary effect persists for 10 or 12 days on each side of apastron, about three-fourths of the period. An attempt was made to establish some connection between the asymmetric nature of the lines, maximum to red or violet, and the position in the period, but nothing definite

was obtained. It is evident, however, that a very slight shift of the position of the maximum, one indeed that would scarcely be noticed in the broad and diffuse lines of this spectrum, would be quite sufficient to account for residuals of the magnitude present on each side of apastron. Such a shift of the maximum might reasonably be assigned to some physical change in the star's atmosphere without the necessity of considering the secondary curve to be due to any deviations from an elliptic orbit caused by the presence of a third body. These, how-

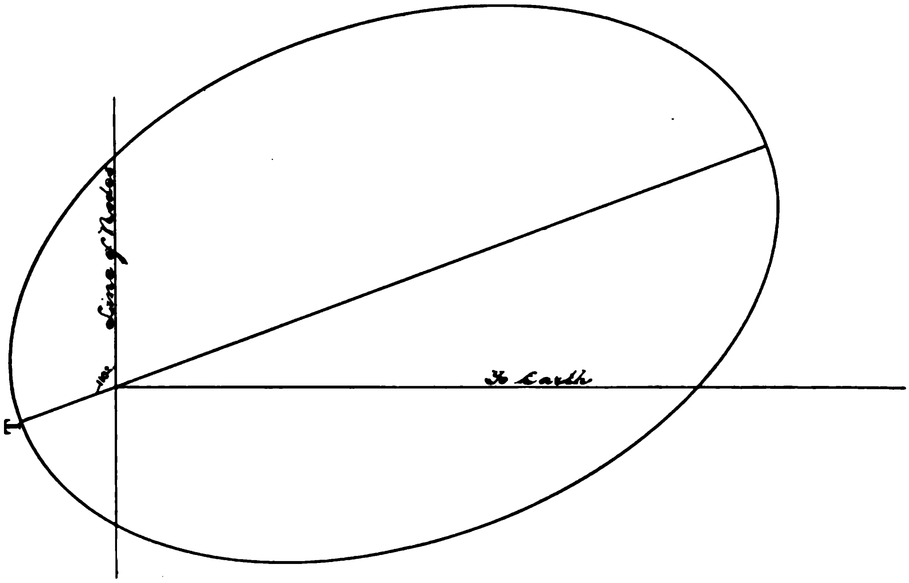


FIG. 2

ever, are speculations which cannot from the data available become anything more.

The remaining elements of the orbit are easily obtained by the well-known methods where, as here, the values of U, e, ω, K, and T are known.

U, or Period,	$=29.136$ days
e	$=0.75$
ω	$=110^\circ$
A, or Positive Maximum,	$=+104$ km
B, or Negative Maximum,	$=-120$ km
K	$=112$ km

T = 1.94 days	= Julian day 2,417,587.94
γ, or velocity of system,	= +20.7 km
$a \sin i$	= 29,680.000 km

A diagram of the orbit showing the proportions of the system is given in Fig. 2.

It is with much pleasure that the advice and encouragement given by the Director, Dr. W. F. King, in the progress of the work are hereby acknowledged.

DOMINION OBSERVATORY
OTTAWA, CANADA
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ON THE ZONAL ERRORS IN MAGNIFICATION OF THE REFLECTING TELESCOPE

By ARTHUR C. LUNN

It is known that in the case of the reflecting telescope in any of its usual forms the principal reason for the smallness of the field of good definition is the presence of coma in the extra-axial point-images, which, if the axial image is well defined, is to be ascribed to the fact that an areal image surrounding the axis is differently magnified by the different zones of the mirror or mirror-system. Abbe, who gave this explanation for the general case of any optical instrument consisting of a centered system of reflecting or refracting surfaces of revolution, showed that the magnification by any zone is

$$m=\frac{\sin u'}{\sin u}, \tag{1}$$

where u' and u are the angles made with the axis by conjugate rays of a central pencil, respectively before and after passage through the zone in question.[1] If the object is at infinity, as in the astronomical case, $\sin u'$ is to be replaced by the linear distance from the axis to the parallel ray incident on that zone, then m will give the ratio of the size of the image to that yielded by an ideal objective of unit focal length. Good definition in the neighborhood of the axis demands the constancy of m for all zones of the aperture, which is the famous "sine-condition" of optical design.

The corresponding errors in the refracting telescope can be removed over a field of a certain size by appropriate design of the component lenses, as in the telescopes used for the astrographic chart and in general those having objectives of the Fraunhofer type. Here the four (or more) refracting surfaces, while so nearly spherical as to be individually far from aberration-free, have their curvatures so chosen that when combined they give the required compensation of their indi-

[1] Czapski-Eppenstein, *Grundzüge der Theorie der optischen Instrumente nach Abbe*, pp. 123 ff.

vidual errors of magnification, simultaneously with a complete or approximate compensation of their axial aberrations, leaving perhaps a residue of the latter to be removed by slight departures from the spherical figures.

There is no theoretical reason why such a compensation could not be effected in the case of a reflecting telescope, consisting of two or more mirrors with their meridian curves so designed that while the individual reflections would in general not be free from aberration on the axis, yet the system as a whole would yield a perfectly defined axial image and at the same time satisfy the sine-condition. An example of such a system has been described by Schwarzschild,[1] consisting of a pair of mirrors resembling the Cassegrainian form, each of which is, for a considerable angular aperture, so nearly a quadric surface of revolution as to admit of separate testing by the use of its geometric foci as optically conjugate; but in neither case are these the conjugate foci proper to the mirror when combined into the system.

For convenience of testing and other reasons it is however desirable, and in existing constructions apparently universal, for each mirror separately to be free from axial aberration through being a quadric surface of revolution having as conjugate optical foci its own geometric foci. The present investigation concerns the question: How far is it possible by suitable choice of the focal lengths of the component mirrors, retaining this practical condition, to diminish the errors due to the departures from constancy of the sine-ratio? The outcome is that for all such systems, of any number of mirrors, those errors are essentially the same, and identical with those pertaining to a simple parabolic mirror of equivalent relative aperture and focal length; so that for any essential improvement of extra-axial definition in this sense, without sacrifice of the illumination of the image through diminution of the effective angular aperture, the condition that each mirror be separately corrected for aberration must be given up.

To find the value of m for a single mirror let e be the eccentricity of the conic section which is its meridian curve; and for definiteness suppose first that this curve is an ellipse of major semi-axis a, and

[1] *Abhandlungen der k. Gesellschaft der Wissenschaften zu Göttingen*, Math. Phys. Klasse, Neue Folge, Band IV, No. 2, 1905.

that an axial pencil is reflected from the farther to the nearer focus at a point of the mirror whose respective distances from the foci are r', r.

If the angles u', u be taken to be acute and of the same sign when the point of reflection is between the vertex of the mirror and the cross-section through the nearer focus, the geometry of the ellipse gives

$$ae+r\cos u=-ae+r'\cos u',\quad r\sin u=r'\sin u',\ r+r'=2a\,, \tag{2}$$

from which by elimination of r, r' comes

$$e=\frac{\sin(u-u')}{\sin u+\sin u'}\,. \tag{3}$$

If u' be eliminated from this equation by means of the relations

$$\sin u'=m\sin u\,,\quad \sin^2 u'+\cos^2 u'=1\,,$$

there results the quadratic equation for m:

$$m^2(1+2e\cos u+e^2)+2me(e+\cos u)-(1-e^2)=0\,.$$

The root -1 is not applicable, being introduced by multiplication by $\sin u+\sin u'$, hence

$$m=\frac{1-e^2}{1+2e\cos u+e^2}\,. \tag{4}$$

A similar deduction shows that equations (3) and (4) apply without change also to the case of the hyperbola, provided that the angles u', u be taken then as having opposite signs, corresponding to the fact that the conjugate foci lie on opposite sides of the mirror, while for the ellipse they are on the same side. This distinction is suitable also for the reason that with the ellipse, for which m is positive, the image and object are inverted with respect to each other, while in the case of the hyperbola, where m is negative, they are relatively erect. Moreover, equation (3) shows that interchange of u and u' simply changes the sign of e, so that the case of reflection from the nearer to the farther focus is accounted for by making e then negative. With these conventions, equation (4) may be regarded as the general expression for the zonal variation of the magnification in terms of the angle u between the axis and the ray after reflection. Since, however, the absolute value of the magnification is not important for the present purpose, but only its relative variations for different zones, it is more convenient to use the ratio of m to the paraxial or ideal magnifi-

cation m_0, the latter being the limiting value of m as u approaches zero, which by (4) is

$$m_0 = \lim_{u \to 0} \frac{\sin u'}{\sin u} = \frac{1-e}{1+e}, \tag{5}$$

so that

$$M = \frac{m}{m_0} = \left\{ 1 - \frac{4e}{(1+e)^2} \sin^2 \frac{u}{2} \right\}^{-1}, \tag{6}$$

a formula which has the advantage of being directly applicable without indeterminateness also to the intermediate case $e=1$, or the parabolic mirror, for which the factor M is analogous to the "blurring factor" defined by Schaeberle[1] and tabulated by him for the extreme aperture of certain important instruments. For all values of u likely to occur in practice with a mirror of given eccentricity e, the value of M may be expanded as a rapidly converging series in even powers of u:

$$M = 1 + \frac{e}{(1+e)^2} u^2 + \dots . \tag{7}$$

where the term in u^2 measures the zonal error of the first order, by far the most important in ordinary cases.

Consider next a system of two mirrors, denoted in optical order by indices 1, 2, respectively, so that $u'_2 = u'_1$. Then the paraxial magnification is

$$m_0 = \frac{1-e_1}{1+e_1} \cdot \frac{1-e_2}{1+e_2}, \tag{8}$$

so that in this regard the system is equivalent to a single mirror of eccentricity e, defined by

$$\frac{1-e}{1+e} = \frac{1-e_1}{1+e_1} \cdot \frac{1-e_2}{1+e_2}, \tag{9}$$

whence

$$e = \frac{e_1+e_2}{1+e_1e_2}. \tag{10}$$

The zonal factor for the first mirror is

$$M_1 = \left\{ 1 - \frac{4e_1}{(1+e_1)^2} \sin^2 \frac{u_1}{2} \right\}^{-1}, \tag{11}$$

while, since interchange of foci changes the sign of the eccentricity and changes the magnification to its reciprocal, the similar factor for the second mirror can be written

$$M_2 = 1 + \frac{4e_2}{(1-e_2)^2} \sin^2 \frac{u_1}{2}. \tag{12}$$

[1] *Astronomical Journal*, **18**, 35, 1897.

Elimination of u_1 from these two equations gives the relation

$$M_1 = \left\{ 1 - \frac{e_1(1-e_2)^2}{e_2(1+e_1)^2}[M_2 - 1] \right\}^{-1}, \tag{13}$$

which is an identity for all zones of the aperture. But M_2 is given also by

$$M_2 = \left\{ 1 - \frac{4e_2}{(1+e_2)^2} \sin^2 \frac{u_2}{2} \right\}^{-1}. \tag{14}$$

Hence the zonal factor for the system is

$$M = M_1 M_2 = \left\{ 1 - \frac{4[e_1(1+e_2)^2 + e_2(1+e_1)^2]}{(1+e_1)^2(1+e_2)^2} \cdot \sin^2 \frac{u_2}{2} \right\}^{-1}, \tag{15}$$

which according to (10) can be written

$$M = \left\{ 1 - \frac{4e}{(1+e)^2} \sin^2 \frac{u_2}{2} \right\}^{-1} \tag{16}$$

in form similar to (6). This shows that the single substitute mirror of eccentricity determined according to (10) by the paraxial magnification is equivalent to the system also in its zonal errors. By induction it follows that a system of n mirrors can be replaced in the same sense by a single equivalent mirror of eccentricity defined by

$$\frac{1-e}{1+e} = \prod_{1}^{n} \frac{1-e_i}{1+e_i}. \tag{17}$$

The proof would need to be modified to cover the cases where e as thus defined becomes indeterminate, but these are of no practical importance.

In any optical combination consisting of a centered system of reflecting surfaces of revolution, each of which is individually corrected for axial aberration, the relative zonal errors of magnification at given points in the final angular aperture are identical with those of a single mirror giving the same paraxial magnification.

In the astronomical case the eccentricity of the first mirror is unity, and the definition of paraxial magnification must be modified accordingly; but equation (17) makes the substitute mirror also parabolic, as it should, and with e so defined the proof for the zonal factor M remains valid, so that the system is equivalent to a simple parabolic mirror of the same linear aperture and focal length. From the present point of view the advantage of the Gregorian and more especially of

the Cassegrainian form of telescope over the Newtonian lies in the increased focal length and consequently diminished angular aperture attainable, with a principal mirror of given linear aperture and a mounting of given size.

CHICAGO, ILLINOIS
February 1908

THE DETERMINATION OF THE HELIOCENTRIC POSITION OF A CERTAIN CLASS OF CORONAL STREAMERS[1]

By JOHN A. MILLER

In his *Mechanical Theory of the Sun's Corona*, Professor Schaeberle assumes that the theoretical corona is caused by light emitted and reflected from streams of matter ejected from the sun by forces, which in general act along lines normal to its surface. These streams are assumed to be formed of a series of particles ejected from the same point of the sun's surface and following each other in such a way that they make a continuous stream. From the laws of mechanics it follows, as Professor Schaeberle points out, that of two particles of the same stream, that particle has the less angular velocity which is at the greater distance from the sun's surface. He further assumes that the streamers which we see are not the actual streams but *rays* that, because of a certain optical principle, result from the orthographic projection of two or more series of streams that intersect each other at a small angle.

In what follows I have used all these assumptions except the last. Instead, and with no thought of controverting this notable and ingenious explanation of the corona, I have assumed that what we see and photograph are the real streams projected orthographically on a plane perpendicular to a line joining the observer's eye and the center of the sun. Throughout the paper I have used the word stream to mean the actual stream of ejected particles and the word streamer to mean the orthographic projection of the stream.

If we grant the above assumptions it is possible to show that some of these streamers will curve away from the projection of the pole of the sun throughout their entire length, some will curve toward it, while a few of them will at first curve away from, and later toward it, or vice versa. For the latter class of streamers, it is possible to find the heliocentric latitude and longitude of a particle at that part

[1] It is a pleasure to acknowledge my obligations to Mr. Walter R. Marriott, instructor in mathematics, Swarthmore College, who has aided me in many ways, but particularly with the rather tedious computations.

of the streamer where it reverses its direction of curvature, the distance of this particle from the sun, the point on the sun's surface from which the particle was ejected, the time it was ejected, and hence the position of the point of ejection at any time; we can also find the velocity with which the particle was ejected, the velocity of the particle at any time, the orbit of each particle in the stream, and the resultant of all forces acting on the particle, and, if we assume the law of the force, we can find the magnitude of any repulsive force, such as light or electric pressure, that may exist. It is further possible to find a rough approximation of the position of streamers of the first two classes.

To prove these assertions, choose as

z-axis, the axis of the sun;

x-axis, the equatorial diameter passing through the west side of the sun;

y-axis, a line perpendicular to the xz-plane.

Let x, y, z be the rectangular heliocentric co-ordinates of any point;

Let ϕ be its heliocentric latitude;

Let θ be its heliocentric longitude, measured from the yz-plane, positive in the direction of the sun's rotation;

Let R be its radius vector;

Let λ be the angle between the z-axis and the line through the observer and the center of the sun;

Let the x- and the z-axis project into a ξ- and η-axis respectively;

Let A be the angle that the projection of a radial line makes with the ξ-axis.

Then,

$$\left.\begin{aligned} x&=R\cos\phi\sin\theta\,,\\ y&=R\cos\phi\cos\theta\,,\\ z&=R\sin\phi\,. \end{aligned}\right\} \tag{1}$$

$$\begin{aligned} \xi&=x,\\ \eta&=z\sin\lambda-y\cos\lambda\,, \end{aligned} \tag{2}$$

$$\tan A=\frac{\sin\lambda\tan\phi-\cos\lambda\cos\theta}{\sin\theta}. \tag{3}$$

Hence all points lying in the plane

$$\tan\lambda\tan\phi-\cos\theta=0$$

will project into the ξ-axis.

All points lying in the plane

$$\cos\phi\sin\theta\tan A-\sin\lambda\sin\phi+\cos\lambda\cos\phi\cos\theta=0$$

will project into a straight line, making an angle A with the ξ-axis. The equation of the line will be

$$\eta - \tan A \cdot \xi = 0.$$

If the force of ejection is normal to the surface of the sun, an ejected particle will move in the plane of a great circle perpendicular to the meridian of the sun through the point of ejection at the time of ejection and tangent to the small circle described by the point of ejection. Hence $\tan A$ will in general be different for different parts of the same streamer. For, let

t_0 = time of ejection,
θ_0 = longitude of P_0, the point of ejection at the time of t_0,
ϕ_0 = latitude of P_0 at the time t_0,
ϕ = latitude of the ejected particle P at any time t,
θ = longitude of P at any time t,
ρ = the projection of the radius vector of P.
Let P'' be the pole of the sun.

Then from the spherical triangle $P_0P''P$

$$\cos(\theta - \theta_0) \tan \phi_0 = \tan \phi \qquad (a)$$

hence

$$-\sin(\theta - \theta_0) \tan \phi_0 = \frac{d}{d\theta}(\tan \phi). \qquad (b)$$

We may differentiate (3) with regard to θ, and by the aid of (b) express

$$\frac{d}{d\theta}(\tan A)$$

as a function of θ and constants. If

$$\frac{d}{d\theta}(\tan A) \equiv 0,$$

the streamer will be a straight line and in this case only. In all other cases $\tan A$ will change, that is, the streamer will curve; for the θ is different for different parts of the stream.

It is at once evident that one, in a rough way, can locate any curved streamer or curved prominence if the curvature is due to the rotation of the sun. Or, better expressed, one can determine whether or not a given streamer comes from a certain large region of the sun. For on any stream the longitude of the points decreases as the distance from the sun increases and $\tan A$ increases or decreases with θ

according as $\frac{d}{d\theta}(\tan A)$ is positive or negative. Hence if $\tan A$ is positive and $\frac{d}{d\theta}(\tan A)$ is positive, the streamer curves away from the pole. If, on the other hand, $\tan A$ is positive and $\frac{d}{d\theta}(\tan A)$ is negative, the streamer curves toward the pole. That is, if the streamer curves away from the pole, θ and ϕ must satisfy equation (3) and the inequality $\frac{d}{d\theta}(\tan A) > 0$. On the other hand, if the streamer curves toward the pole, θ and ϕ must satisfy equation (3) and the inequality $\frac{d}{d\theta}(\tan A) < 0$. If one selects from the regions thus limited those regions from which streams visible during an eclipse may issue, he may obtain in many instances fairly approximate values of θ and ϕ. If one makes the further assumption (not far from the truth in low latitudes) that $\frac{d}{d\theta}(\tan \phi) = 0$ there results the very simple form,

$$\frac{d}{d\theta}(\tan A) = \frac{\cos \lambda - \sin \lambda \tan \phi \cos \theta}{\sin^2 \theta}.$$

The position of streamers of the third class, that is, those that for a part of their length curve away from the pole and for the remainder of their length toward it, may be found exactly. For $\tan A$ increases (or decreases) for a part of the streamer and then decreases (or increases) for the remainder if, and only if, $\frac{d}{d\theta}(\tan A)$ changes sign; that is, passes through infinity or zero. $\frac{d}{d\theta}(\tan A)$ passes through infinity if $\tan \phi = \infty$, or $\sin \theta = 0$; that is, for streams at pole of the sun or in the yz-plane. In either case $A = 90°$. Hence θ and ϕ for the point of a streamer where it reverses its direction of curvature satisfy the equation $\frac{d}{d\theta}(\tan A) = 0$.

Solving this equation simultaneously with (3), (*a*), and (*b*), we get

$$\tan \theta = \frac{\tan A + \cos \lambda \tan (\theta - \theta_0)}{\cos \lambda - \tan A \tan (\theta - \theta_0)} \tag{4}$$

$$\tan \phi = \frac{\cot \lambda}{\sin \theta \tan (\theta - \theta_0) + \cos \theta}. \tag{5}$$

Projecting R on the ξ-axis we have

$$R = \frac{\rho \cos A}{\cos \phi \sin \theta} \tag{6}$$

A and ρ can be measured on the photograph, and hence equations (4), (5), and (6) determine exactly the heliocentric position and the radius vector of the point in a streamer where it reverses its direction of curvature provided we can find $\theta - \theta_0$.

I have assumed that the force of ejection is normal to the sun's surface, and therefore, because of the velocity imparted to the particle by the sun's rotation, the direction of the initial velocity will not be along a normal to the sun. I have assumed also that after the particle is ejected the resultant of all forces acting on it—the sun's attraction and light or electric pressure—is a central force passing through the center of the sun and that it varies inversely as the square of the distance from the center. Each particle of the stream will therefore describe an ellipse,[1] one focus of which—the one near perihelion—will be the center of the sun. It seems reasonable to suppose that all the particles of the stream have been ejected with the same velocity, and, since they are issuing from the same point on the sun, the major axis and the eccentricity of the orbits of all the particles are equal, though the planes of the orbits are different.

It is necessary to measure, in addition to A and ρ, $a(1+e)$, the greatest distance from the center of the sun that the stream attains. Before this is possible θ and ϕ must be approximately known, since the projection of $a(1+e)$ is all that we can measure. A first approximation of the values of θ and ϕ may be obtained by assuming that

$$\frac{d}{d\theta}(\tan \phi) = 0.$$

With this assumption (4) and (5) become

$$\tan \theta = \frac{\tan A}{\cos \lambda} \tag{4'}$$

$$\tan \phi = \frac{\cot \lambda}{\cos \theta} \cdot \tag{5'}$$

The value that one obtains of $a(1+e)$ is somewhat uncertain. A definite minimum value may be assigned to it since it cannot be less than its measured value. Its maximum value, however, is much

[1] Or parabola or hyperbola. The curves on the plate discussed later are ellipses.

less definite. The stream may not have reached its greatest height or the entire stream may not have been photographed. However, all streamers broaden as they recede from the sun and the abrupt curvature of many streamers near their upper extension leads one to believe that he may be guided somewhat by the shape of the streamer and that he can assign a reasonably definite maximum limit. Besides, as can be easily verified by computation, one can change $a(1+e)$ within fairly large limits without affecting large changes in θ and ϕ.

To complete the solution,

Let P be a particle at that point of the streamer where the curvature reverses its direction;

Let P_0 be the point on the sun from which P was ejected;

Let P' be a particle at any point in the streamer;

Let P'_0 be the point of ejection of P';

Let t be the time at which the photograph was made;

Let t_0 and t'_0 be the time when P and P' left the sun respectively;

Let θ, ϕ, R, w=respectively, the longitude, latitude, radius vector, and true anomaly of P at the time of t;

Let θ_0, ϕ_0, R_0, w_0=respectively like values for P_0 at time t_0;

Let θ', ϕ', R', w'=respectively like values for P' at time t';

Let θ'_0, ϕ'_0, R'_0, w'_0=respectively like values for P'_0 at time t'_0;

Let v_2=velocity of ejection;

Let v_1=velocity of the particle due to the sun's rotation;

Let V=velocity with which the particle left the sun;

Let e=eccentricity of the orbits;

Let a=semimajor axis of the orbits;

Let ω=angular velocity of the sun;

Let n=the mean motion in the orbit;

Let C^2=the constant entering into the differential equations of motion;

Let ψ=angle between the normal to the sun and the initial velocity.

In addition to equations (4), (5), and (6) we have from spherical triangles,

$$\tan(\theta-\theta_0)=\frac{\tan(w-w_0)}{\cos\phi_0} \tag{7}$$

$$\tan(\theta'-\theta_0)=\frac{\tan(w'-w'_0)}{\cos\phi_0} \tag{8}$$

$$\tan\phi_0=\frac{\tan\phi}{\tan(\theta-\theta_0)}\,. \tag{9}$$

Now a large change in θ produces a small change in ϕ except in very high latitudes. Hence if we choose for P' the point in the streamer at the edge of moon's shadow, we can without sensible error put $\phi' = \phi_0$. Substituting this value of ϕ' in (3) we may solve for θ'. We may now solve for R'. Since the particles travel in ellipses we have,

$$R = \frac{a\,(1-e^2)}{1+e\cos w} \qquad (10)$$

Since four values of R are known, (10) yields four equations. Also

$$a\,(1+e) = \text{some measured quantity}, \qquad (11)$$

$$t - t_0 = \int_{R_0}^{R} \frac{R\;dR}{a\sqrt{(a^2e^2-(a-R)^2}} \qquad (12)$$

This yields two equations.

We have also

$$n^2a^3 = C^2 \qquad (13)$$

$$\tan\psi = \frac{v_1}{v_2}$$

$$4a^2e^2 = R^2{}_0 + (2a-R_0)^2 + 2\,R_0\,(2a-R_0)\cos 2\psi \qquad (14)$$

$$V_1 = \omega R_0 \cos\phi_0 \qquad (15)$$

$$v_1^2 + v_2{}^2 = V^2$$

$$V^2 = C^2\left[\frac{2}{R_0} - \frac{1}{a}\right] \qquad (16)$$

$$\theta_0' - \theta_0 = \omega(t_0' - t_0). \qquad (17)$$

This is a sufficient number of equations to solve the problem completely.

I have made an application of the preceding theory to the large-scale photographs made by Professor W. A. Cogshall and myself at Almazan, Spain, during the total solar eclipse of August 30, 1905. These photographs were made with a lens of nine inches aperture and sixty feet focal length, mounted with its axis horizontal; the light being reflected into it by means of a coelostat. The weather on the day of the eclipse was disappointing. For two hours before totality the entire sky was covered with light though unbroken clouds. At the time of totality, however, the clouds in the immediate vicinity of the sun appeared to break away and the inner corona shone through light drifting clouds. The photographs show a very great deal of coronal detail, though they lack some of the definiteness that would have come from good seeing. The clouds made it impossible

to register very long streamers—the longest one photographed being about three-fourths that of the sun's diameter.

From the negative made near the time of mid-totality, a series of positives was made, each positive being printed deeper than the preceding one. On the thinnest positives the detail near the sun was lost, while on the densest positives the detail at a short distance from the sun was printed out. By the aid of this series it was possible to trace a given streamer throughout its entire length.

The general appearance of the corona over the region of the great prominences on the eastern limb of the sun indicates a very complex structure. The streamers there are not radial and their directions away from the sun are so random as compared with simpler structure at other places that one can hardly escape the impression that they have been influenced by the prominences. Practically all the streamers curve, and curve regularly, though not uniformly. Most of them are nearly radial near the base, and curve much less rapidly there than at some distance from the sun, qualitatively, at least, as a stream of matter ejected from the sun would do. The diameter of nearly every streamer is smaller near the base than at the top. Of 63 streamers, which were all that seemed to me to be well defined, the bases of 18 were inclined north of the center of the sun and the bases of 6 were inclined south of the center; 39 curve toward the equator, and 14 away from it. The remaining ones, so far as I could tell, were perfectly straight.

In addition to these I found five streamers—four on the west, and one on the east margin of the sun—that had double curvature. All curved first away from the pole, then toward it. I chose three of these streamers, all on the west limb of the sun, for discussion. Two of them were apparently near each other, the remaining one separated some distance from these. Denote by A and A', respectively, the angle A where the streamer reverses its direction of curvature (in our case where the streamer begins to curve toward the pole) and where the streamer meets the margin of the shadow. I measured these angles with a protractor that read to minutes, setting the protractor five times and measuring the angle four times at each setting. The table below contains the means of these measures as well as those of ρ.

Streamer	No. 1	No. 2	No. 3
A	$2^\circ\ 25'$	$11^\circ\ 09'$	$59^\circ\ 38'$
A'	$3\ \ 34$	$12\ \ 45$	$62\ \ 27$
ρ	$\frac{474}{446}\ R_0$	$\frac{510}{446}\ R_0$	$\frac{520}{446}\ R_0$

Computing λ we find

$$\lambda = 84^\circ\ 42'.$$

Using formulas (4′), (5′), and (6) we find the following approximate values:

Streamer	No. 1	No. 2	No. 3
θ	$24^\circ\ 33'\ 20''$	$64^\circ\ 53'\ 24''$	$86^\circ\ 54'\ 07''$
ϕ	$5\ \ 49\ \ 25$	$12\ \ 19\ \ 52$	$59\ \ 46\ \ 35$
R	$2.574\ R_0$	$1.271\ R_0$	$1.183\ R_0$

These values must be regarded as very rough approximations.

The values that one may now obtain for $t-t_0$ and for θ' show beyond question either that the assumptions that were made regarding the formation of the streams were wrong, or that some other force than the attraction of the sun was acting on the particle after its ejection and that this force is a repulsive force. Choosing the latter alternative, we assumed that whatever this force may be its magnitude varies inversely as the square of the distance of the particle from the sun, and treated rigorously streamer No. 1, according to the methods developed in this paper. For this streamer we have the following data:

$$A = 2^\circ\ 25',$$
$$A' = 3^\circ\ 34',$$
$$\rho = \frac{474}{446}\ R_0,$$
$$a\ (1+e) = 2.5\ R_0.$$

Solving equations (3) to (17) we get the following values:

$\theta = 54^\circ\ 33'$, $\theta' = 58^\circ\ 19'$, $a = 1.635 R_0$, $\phi_0 = 5^\circ\ 49'\ 22''$,
$\phi = 5\ \ 02\ \ 49$, $\phi' = 5\ \ 49\ \ 22$, $e = 0.529$, $t-t_0 = 251{,}860$ seconds,
$R = 1.3144\ R_0$, $R' = 1.179$, $\theta_0 = 24^\circ\ 33'$, $v_2 = 0.6$ miles per second.

The repulsive force is 0.99 the attraction of the sun.

That is, the particle P at the point of the streamer where it reverses its direction of curvature left the sun 251,860 seconds before the eclipse occurred. The longitude and the latitude of the point of ejection when the particle was ejected were $24^\circ\ 33'$ and $5^\circ\ 49'\ 22''$

respectively. At the time of the eclipse P was 1.3 radii of the sun from its center.

The force of repulsion is surprisingly large and hence the velocity of ejection very small. These results are entirely consistent with the conclusions reached by Campbell and Perrine (*L. O.* ***Bulletin*** No. 115), and confirm in a measure the conclusions of Arrhenius (*L. O.* ***Bulletin*** No. 58).

One cannot draw general conclusions from one plate or one streamer, but the nature of these results is such as to warrant the reduction of others of the numerous large-scale photographs of the solar corona made since 1893.

SWARTHMORE COLLEGE
SWARTHMORE, PA.
March 21, 1908

METALLIC ARCS FOR SPECTROSCOPIC INVESTIGATIONS

By A. H. PFUND

In connection with some work which I have been doing recently on the redetermination of the wave-lengths of the iron lines according to the method of Fabry and Perot, it has been found not only desirable but imperative that the iron arc should burn steadily, without wandering or flickering. If one may judge from the most recent literature on the subject,[1] it is considered most difficult, if not impossible, to realize this condition for any desired length of time. Recently, however, I have constructed a simple type of iron arc which burns with an almost perfect steadiness and without the least attention for an hour or more. As the iron arc is so universally employed in spectroscopy, and as this new construction makes it a pleasure instead of a burden to work with this type of arc, I have thought it worth while to present the following note on the subject.

Although the iron arc usually jumps about in a most erratic manner, it does occasionally settle down and burn steadily. If, at such a time, the arc be viewed through a piece of smoked glass, it is found that the discharge proceeds from a bead of molten iron oxide on the lower electrode and terminates on a small bright patch on the upper electrode. This upper electrode, if it form the negative pole, becomes hollowed out in time to form a crater. The difficulty with this arrangement is that the bead of molten iron oxide soon rolls off the electrode and the wandering of the arc once more sets in. In order to realize permanently the conditions which existed while the arc was burning steadily, the construction shown in Fig. 1 was adopted.

The lower (positive) electrode (*a*), consisting of a rod of iron about 12 mm in diameter, carries a bead of iron oxide (*b*) in a small cup-shaped bowl. The upper electrode (*c*), an iron rod about 6 mm in diameter, is made to project by 3 mm from a brass bushing (*d*) fastened to the rod by a set-screw (*e*). This is done to prevent the electrode from getting too hot. Such an arc burns best if sup-

[1] P. Eversheim, *Astrophysical Journal*, **26**, 172, 1907; *Zeitschrift für wiss. Photographie*, **5**, 152, 1907.

plied with about 3.5 amperes from a 220-volt direct-current circuit. After the electrodes are carefully centered, the arc can usually be started by bringing the two electrodes into contact and then separating them. If this fails, the desired result can be brought about by bridging the gap between the electrodes by means of a carbon rod, or by heating the bead of oxide to red heat by means of a Bunsen burner and then bringing the electrodes into contact. It is best to limit the length of arc to about 6 mm. After burning for an hour or more, the upper electrode becomes incrusted with a layer of iron oxide which forms the crater already alluded to. Before starting the arc anew it is best to knock off this crust and to readjust the brass bushing.

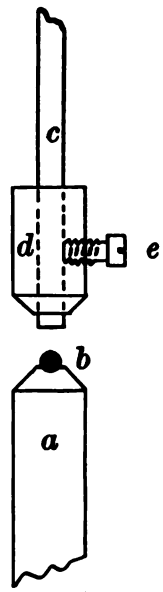

Fig. 1

In attempting to apply this same construction to arcs of other metals it was found, as for example in the case of copper, that if the upper electrode were also made of copper the arc behaved very badly. Therefore the following general construction was adopted, which works perfectly for the metals thus far tried, viz., iron, nickel, cobalt, copper, silver, and platinum. The iron rod already described forms the lower (positive) electrode while a rod of carbon about 1 cm in diameter forms the upper electrode. In order to produce a copper arc a bead of copper oxide is placed on the lower electrode and the arc is started. Having prepared beads of the different metals or their oxides and having placed these beads in properly labeled pill-boxes, all that is necessary to change from, say, the copper arc to the nickel arc is remove the copper bead by means of a pair of tweezers and to replace it by a nickel bead. The method is as simple as it is satisfactory.

A bead of any metal may be made by placing a small piece of the metal in question on the lower electrode. Upon starting the arc, the bead is formed immediately. If it is found that the bead is too small, its size can be increased by feeding some wire of the same metal into the bead while the arc is burning. The bead ought to be about 3 mm in diameter. It is to be emphasized in this connection that the condition essential to the proper behavior of the arc

is that the bead of molten metal or oxide be in the spheroidal state and that it bulge out considerably above the edges of its receptacle—as is shown in Fig. 1.

Of the various metals tried, the only one which at first gave trouble was silver. It was found that a bead of silver when placed upon the 12 mm iron rod failed to melt—and in consequence the arc was not steady. By using a carbon rod in place of the iron, this silver bead became as fluid as water and shot out minute globules of metallic silver. The proper conditions, which evidently lay between these two extremes, were finally realized by placing the bead on a rod of iron but 7 mm in diameter. This rod became sufficiently hot to keep the silver in a molten condition without getting it too hot. Under these conditions the arc behaves perfectly. In the case of platinum either a carbon or a thin iron rod may be used.

These arcs, in which carbon is used as one electrode, may be drawn out to the length of about an inch and still behave satisfactorily. The current may also be increased beyond 3.5 amperes. Comparing the spectrum of the iron arc produced when the upper electrode is of iron with that produced when the upper electrode is of carbon, it is found (as has been known before) that in the latter case the spectrum is very much weaker and that the lines in the visible region are relatively more weakened than those in the ultra-violet. A study of the Fabry and Perot fringe system shows that the lines produced by this carbon-iron arc rival in homogeneity and sharpness the red and green lines of cadmium produced in a vacuum arc.

Johns Hopkins University
March 1908

A NEW MERCURY LAMP

By A. H. PFUND

The following is the description of a simple form of mercury vapor arc, adapted for use in the visible as well as the ultra-violet spectrum and capable of being made by anyone familiar with the rudiments of glass-blowing. As will be seen from Fig. 1, the lamp consists of a piece of glass tubing about 7 cm in length and 1.2 cm in diameter, to which there is sealed a larger tube, 3 cm in diameter and 18 cm in length. A side tube is sealed on this larger portion for the purpose of exhaustion. A platinum wire is sealed into the lower end of the smaller tube, which is then filled with clean mercury to a height of about 3 cm. The mercury forms the negative electrode, while a hollow sheet-iron electrode forms the positive. This electrode is made by cutting out a piece of sheet-iron as shown in Fig. 2 (*a*) which is subsequently bent into the form shown in Fig. 2 (*b*). The lower portion of this lectrode is of somewhat smaller diameter than the upper, and, when in place, does not touch the glass tube at any point. This construction is adopted for the reason that the arc, which terminates on the lower ring of this electrode, raises it to red heat—and if this portion of the electrode were in contact with the glass, a crack would result. The positive electrode is about 1 cm above the mercury and is held in place by friction. The current is led into this electrode by means of an iron wire passing along the length of the tube and out at the top. As the iron wire is considerably heated by the current and as under these conditions there is a tendency to soften the sealing-wax, through which this wire passes, it

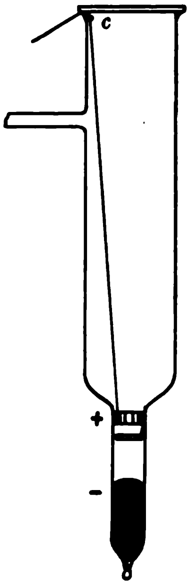

FIG. 1

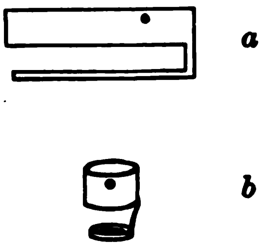

FIG. 2

is advisable to fuse a piece of copper wire to the iron, as shown in Fig. 1 at (*c*). The copper wire must be shellaced thoroughly to keep it from being amalgamated. The top of the lamp is closed by a quartz plate, the air-tight seal being effected by means of sealing-wax.

The lamp is next exhausted on a mercury air-pump and it is best to run and heat the lamp while it is still on the pump so as to drive off the water vapor and the gases contained in the electrodes. After carrying the exhaustion to as high a degree as possible, the lamp is sealed off from the pump and is ready for use.

The lamp burns in a vertical position and consumes from 1.4 to 1.6 amperes supplied from a 110-volt direct-current circuit. The arc is readily started by heating the lower, mercury-filled portion by means of a Bunsen burner. Either by tilting the lamp or by giving it a sudden, upward jerk, contact is made between the two electrodes and the discharge sets in. If the light in the visible spectrum alone is required, it may be taken out through the side of the tube, but if the ultra-violet is also needed, it is taken out through the quartz window at the top. A totally reflecting quartz prism or a speculum mirror gives the light a horizontal direction.

After the lamp has been running for several days it is found that gases are liberated and as a result the arc becomes so hot that the glass softens and eventually sucks in. It is easy, however, to avoid this by testing, from time to time, whether the glass is getting too hot. If paper, upon being held against the glass, is charred, it is time to stop the discharge and to re-exhaust.

Without discussing in detail the various advantages of this type of mercury lamp, it may be stated that the lamp lasts for a long time and that, without applying strips of wet cloth to the upper portion of the large tube, it remains cold and no mercury condenses on the quartz window.

Johns Hopkins University
March 1908

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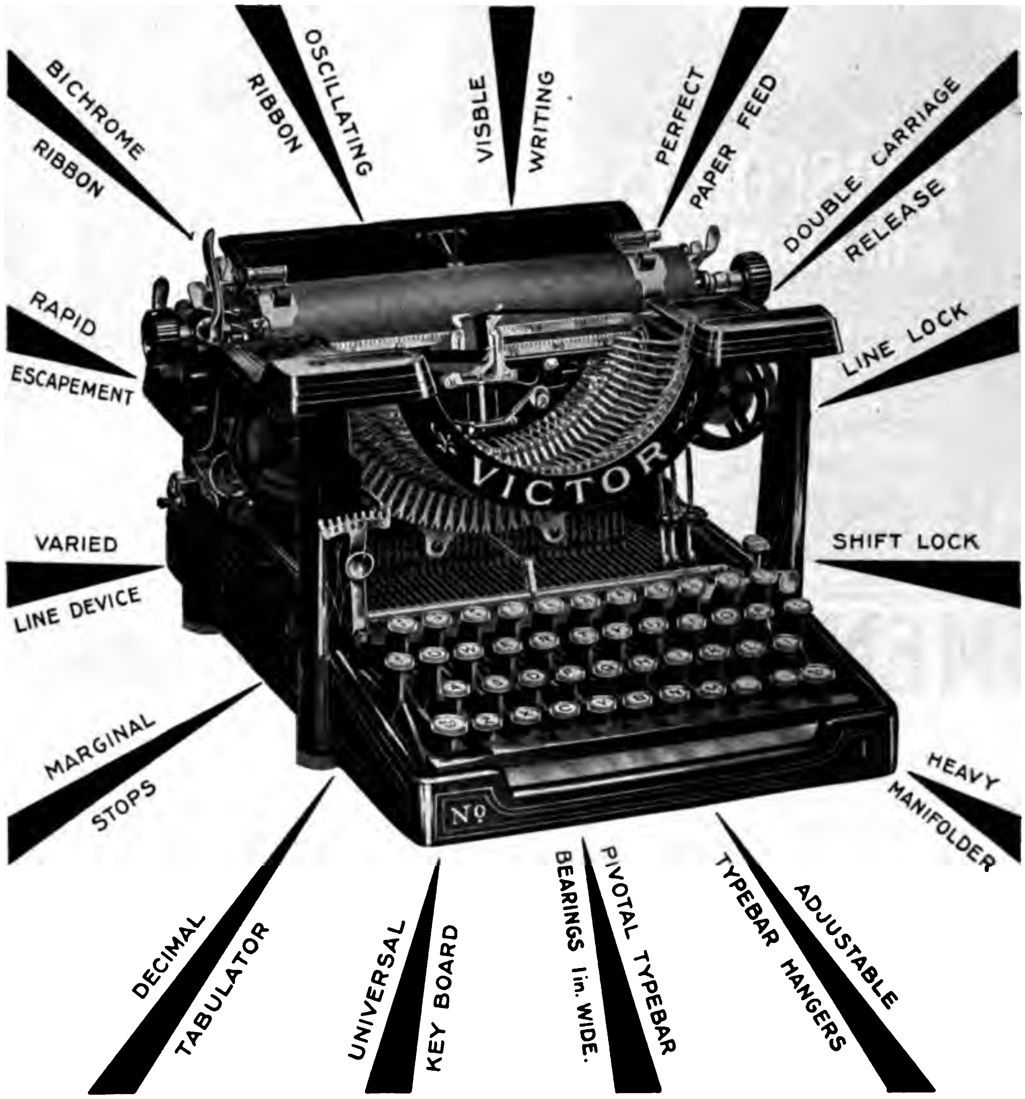

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THE ASTROPHYSICAL JOURNAL

An International Review of Spectroscopy and Astronomical Physics

EDITED BY

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CONTENTS

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VOLUME XXVII JUNE 1908 NUMBER 5

RADIAL VELOCITIES OF 99 STARS OF THE SECOND AND THIRD SPECTRAL CLASSES OBSERVED AT BONN

By F. KÜSTNER

During the years 1903 to 1907 I have, in collaboration with Dr. W. Zurhellen, obtained spectrograms of nearly all stars of the second and third spectral classes down to the fourth visual, or fifth photographic magnitude, which could be observed in Bonn, using the photographic refractor by Repsold and Steinheil of aperture 30 cm, and focal-length 5.1 m. The radial velocities resulting from provisional computations are briefly communicated herewith. The definitive results will be published later *in extenso* in the *Veröffentlichungen der Bonner Sternwarte*, but they will not differ much from the values given here.

The spectrograph employed was constructed by Töpfer of Potsdam, and has three 60° prisms of heavy Jena flint, which are set at the minimum of deviation for $H\gamma$. The height of the prisms is 32 mm, and the lengths of their sides are 52, 54, and 56 mm. The collimating lens is of 28 mm aperture and 450 mm focal-length, and the camera lens of 30 mm aperture and 361 mm focal-length. The spectrum is sharply defined from λ 4150 to λ 4500. At medium temperature the dispersion is as follows:

λ	Dispersion for One Tenth-Meter	Tenth-Meters per mm
4200	46″2 = 0.081 mm	12.4
4300	39.8 0.070	14.4
$H\gamma$	37.6 0.066	15.2
4400	34.6 0.061	16.5
4500	30.6 0.054	18.7

The spectrograph is automatically kept at constant temperature by electric means. The light of the iron arc has served for comparison after being diffusely projected through a ground-glass disk upon the slit. From two to five exposures of the comparison spectrum are made, according to the length of the exposure on the star.

A microscope by Töpfer, the screw of which has a pitch of $\frac{1}{4}$ mm, has served for the measurement of the spectrograms. The spectrograms of the first year, 1903, were measured both by myself and by Zurhellen, and my measurements are distinguished in the following list by a * attached to the plate number. The results of the two observers may be regarded as practically independent, inasmuch as we intentionally observed lines as different as possible. I have already published in detail these measurements in 1903, in *Astronomische Nachrichten*, Nos. 3972–73 (**166**, 177, 1904); the results must be briefly repeated, however, in connection with the subsequent measures. The spectrograms of the years 1904 to 1907 were all measured by Mr. Zurhellen alone, who has carried out this arduous work with great care. All the measures were in every case made in both positions of the plate, with red to right and red to left, and the mean was used in the computations. The wave-lengths of the *Fe* lines, as a rule extending from λ 4210 to λ 4482, were taken from Kayser, the wave-lengths of the stellar lines, from λ 4220 to 4475, from Rowland.

The following tabulation of the resulting radial velocities requires little explanation. Below the name of the star is given the right ascension and declination for 1900, the spectral type according to Miss Maury (*Harvard Annals*, **28**) and the photographic magnitude according to the *Draper Catalogue* (*Harvard Annals*, **27**). The column "Exposure" gives the duration in minutes, in parentheses when there was interference by clouds, and the initial of the observer, K or Z; in taking some plates the observers exchanged places, which is indicated by KZ. The column "Red. to ⊙" contains the sum of the annual and daily components of the velocity of the earth, the first being computed by Schlesinger's table in the *Astrophysical Journal* (**10**, 1, 1899). The last two columns contain the number m of the star lines measured and the average deviation $\frac{1}{m}\Sigma v$ of the separate lines from the mean for the plate.

δ Andromedae

α 0h 34m.0, δ +30° 19′ Type XV, Mag. 4.79

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\Sigma v$
		min.		km	km	km		km
492	1905, Oct. 20.424	(110) Z	0h 1m	+ 1.48	− 3.45	− 1.97	16	±1.9
777	1906, Oct. 8.495	105 Z	+0 52	− 5.75	+ 2.20	− 3.55	17	3.3
793	1906, Nov. 10.433	120 Z	+1 34	+ 9.81	−12.92	− 3.11	14	1.8
1009	1907, Nov. 1.451	120 Z	+1 24	+ 3.32	− 8.85	− 5.53	20	1.7

Mean: − 3.54

α Cassiopeiae

α 0h 34m.8, δ +56° 0′ Type XV, Mag. 3.88

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\Sigma v$
278	1904, Oct. 19.416	51 K	−0 15	− 5.73	+ 3.38	− 2.35	16	±1.7
281	1904, Oct. 27.430	53 K	+0 36	− 2.43	+ 0.52	− 1.91	15	1.4
510	1905, Nov. 30.303	62 K	−0 15	+ 7.91	−10.97	− 3.06	20	2.1
820	1906, Dec. 23.221	60 K	−0 43	+14.43	−16.92	− 2.49	25	1.7

Mean: − 2.45

β Ceti

α 0h 38m.5, δ −18° 32′ Type XV, Mag. 3.86

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\Sigma v$
311	1905, Jan. 1.238	60 K	+0 16	+42.33	−27.93	+14.40	16	±1.8
313	1905, Jan. 2.230	60 K	+0 8	+43.01	−27.84	+15.17	15	1.6
525	1905, Dec. 18.285	70 K	+0 26	+43.27	−28.22	+15.05	16	1.3
1031	1907, Nov. 21.350	85 K	+0 12	+38.60	−23.85	+14.75	17	1.9

Mean: +14.84

η Cassiopeiae

α 0h 43m.0, δ +57° 17′ Type XIII, Mag. 4.73

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\Sigma v$
751	1906, Aug. 29.545	105 Z	−0 42	− 7.40	+17.83	+10.43	25	±2.0
802	1906, Nov. 23.297	112 Z	−1 00	+18.88	− 7.75	+11.13	25	2.8
808	1906, Dec. 18.241	100 Z	−0 42	+23.38	−15.11	+ 8.27	19	2.7
1008	1907, Nov. 1.364	100 Z	−0 51	+ 9.71	− 0.04	+ 9.67	20	1.4

Mean: + 9.88

β Andromedae

α 1h 4m.1, δ +35° 5′ Type XVII, Mag. 4.57

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\Sigma v$
537	1905, Dec. 31.261	80 K	+0 18	+27.31	−25.65	+ 1.66	29	±2.1
540	1906, Jan. 1.260	90 K	+0 21	+27.22	−25.81	+ 1.41	26	2.5
821	1906, Dec. 23.311	90 K	+0 58	+25.25	−24.12	+ 1.13	19	2.4
1016	1907, Nov. 4.443	100 Z	+0 54	+ 7.91	− 6.17	+ 1.74	20	2.3

Mean: + 1.49

α Ursae minoris

α $1^h\ 22^m.6$, δ +88° 46′ Type XIII, Mag. bright

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/wΣv
		min.		km	km	km		km
104*	1903, July 2.371	60 K	− $9^h 20^m$	−17.45	+ 2.57	−14.88	16	±1.6
104	1903, July 2.371	60 K	− 9 20	−16.13	+ 2.57	−13.56	18	2.4
106*	1903, July 4.470	79 K	− 6 50	−18.70	+ 2.99	−15.71	17	2.3
106	1903, July 4.470	79 K	− 6 50	−19.51	+ 2.99	−16.52	17	1.8
408	1905, May 30.361	50 K	−11 43	− 7.77	− 3.88	−11.65	16	2.0
410	1905, May 31.369	25 K	−11 27	−11.43	− 3.69	−15.12	14	2.7
414	1905, June 19.371	40 K	−10 10	−13.41	+ 0.08	−13.33	16	2.5

Velocity variable

η Piscium

α $1^h\ 26^m.1$, δ +14° 50′ Type XIV, Mag. 5.02

293	1904, Nov. 15.398	122 Z	+0 13	+28.67	−14.24	+14.43	14	±1.5
505	1905, Nov. 27.383	(100)Z	+0 37	+34.04	−19.38	+14.66	17	1.8
837	1907, Jan. 24.261	100 Z	+1 30	+45.66	−29.93	+15.73	18	1.9
1033	1907, Nov. 22.435	108 Z	+1 31	+31.41	−17.14	+14.27	16	1.7

Mean: +14.77

υ Persei

α $1^h\ 31^m.8$, δ +48° 7′ Type XV, Mag. 5.10

515	1905, Dec. 1.422	100 Z	+1 44	+29.12	−11.81	+17.31	16	±3.0
830	1907, Jan. 23.253	100 Z	+1 9	+42.68	−24.41	+18.27	19	2.6
839	1907, Jan. 26.245	100 Z	+1 9	+43.05	−24.56	+18.49	25	1.9
1036	1907, Dec. 4.306	105 Z	−0 54	+31.21	−12.56	+18.65	16	1.7

Mean: +18.18

γ Andromedae, maj. dpl.

α $1^h\ 57^m.8$, δ +41° 51′ Type XV, Mag. 4.05

290	1904, Nov. 14.448	53 K	+0 49	− 5.19	− 4.67	− 9.86	16	±1.4
320	1905, Jan. 8.340	50 K	+1 51	+13.50	−24.35	−10.85	15	1.4
557	1906, Jan. 17.272	65 K	+0 47	+15.69	−25.71	−10.02	16	2.6
1020	1907, Nov. 5.464	75 Z	+0 34	−10.82	− 0.16	−10.98	20	1.7

Mean: −10.43

α Arietis

α $2^h\ 1^m.5$, δ +23° 0′ Type XV, Mag. 4.13

259	1904, Aug. 25.601	40 Z	−0 52	−38.37	+25.94	−12.43	20	±2.0
295	1904, Nov. 16.382	51 Z	−0 42	− 2.21	− 9.35	−11.56	20	1.9
299	1904, Dec. 21.325	45 K	+0 14	+10.68	−23.95	−13.27	20	1.8
314	1905, Jan. 2.283	40 K	0 0	+12.75	−27.11	−14.36	20	1.5
507	1905, Nov. 28.374	50 Z	−0 6	+ 2.70	−14.94	−12.24	20	2.0
558	1906, Jan. 22.224	50 K	−0 6	+16.66	−29.66	−13.00	20	1.9

Mean: −12.81

ξ' *Ceti*

α 2h 7m.7, δ +8° 23′ Type XIV ?, Mag. 5.09

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
		min.		km	km	km		km
526	1905, Dec. 18.369	120 Z	+0h59m	+23.74	−24.44	− 0.70	14	±3.3
824	1907, Jan. 22.264	120 Z	+0 44	+22.46	−30.20	− 7.74	23	3.0
843	1907, Jan. 29.251	120 Z	+0 53	+20.60	−30.05	− 9.45	17	2.1
1037	1907, Dec. 16.405	120 Z	+1 41	+15.27	−23.65	− 8.38	16	1.8

Velocity variable

o Ceti, dark lines

α 2h 14m.3, δ −3° 26′ Type XX, Mag. var.

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
804	1906, Dec. 7.377	100 Z	+0 20	+87.14	−20.60	+66.54	16	±3.9
810	1906, Dec. 18.351	90 KZ	+0 26	+92.25	−24.16	+68.09	13	4.9
818	1906, Dec. 22.354	100 KZ	+0 46	+89.06	−25.27	+63.79	14	3.4

Mean: +66.14

o Ceti, $H\gamma$ bright line

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
804	1906, Dec. 7.377	100 Z	+0 20	+71.10	−20.60	+50.50	1	
807	1906, Dec. 12.356	(40) Z	+0 9	+75.00	−22.30	+52.70	1	
809	1906, Dec. 18.305	20 K	−0 40	+73.95	−24.06	+49.89	1	
810	1906, Dec. 18.351	90 KZ	+0 26	+76.93	−24.16	+52.77	1	
813	1906, Dec. 21.302	16 K	−0 33	+75.40	−24.90	+50.50	1	
817	1906, Dec. 22.310	17 K	−0 18	+72.85	−25.18	+47.67	1	
818	1906, Dec. 22.354	100 KZ	+0 46	+76.97	−25.27	+51.70	1	
822	1906, Dec. 23.362	12 K	+1 2	+74.20	−25.55	+48.65	1	

Mean of 4 long expos.: +51.92
Mean of 4 short expos.: +49.18

α *Ceti*

α 2h 57m.1, δ +3° 42′ Type XVII, Mag. 4.63

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
300	1904, Dec. 21.396	100 Z	+1 1	− 2.37	−21.61	−23.98	10	±2.0
528	1905, Dec. 25.383	100 K	+0 57	− 0.71	−22.89	−23.60	14	2.1
555	1906, Jan. 16.292	120 KZ	+0 13	+ 5.89	−28.18	−22.29	17	3.1
852	1907, Feb. 5.247	100 Z	+0 26	+ 5.57	−29.46	−23.89	12	2.2

Mean: −23.44

γ *Persei*

α 2h 57m.5, δ +53° 7′ Type XIV, Mag. 4.01

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
527	1905, Dec. 18.463	70 K	+2 23	+14.77	−11.78	+ 2.99	17	±2.5
567	1906, Jan. 23.292	80 K	+0 40	+23.76	−22.39	+ 1.37	18	3.2
831	1907, Jan. 23.341	75 K	+1 50	+22.83	−22.40	+ 0.43	13	1.6
853	1907, Feb. 7.255	70 K	+0 44	+25.89	−24.39	+ 1.50	19	2.4

Mean: + 1.57

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
			κ Persei					
	$\alpha\ 3^h\ 2^m.7,\ \delta+44°\ 29'$			Type XV, Mag. 5.12				
		min.		km	km	km		km
328	1905, Jan 14.333	120 Z	$+0^h59^m$	+53.38	−22.99	+30.39	16	±1.4
529	1905, Dec. 26.397	115 K	+1 16	+47.24	−16.92	+30.32	17	2.8
823	1907, Jan. 13.370	(120)Z	+1 47	+53.73	−22.63	+31.10	22	1.6
					Mean:	+30.60		
			α Persei					
	$\alpha\ 3^h\ 17^m.2,\ \delta+49°\ 30'$			Type XII*ac*, Mag. bright				
264	1904, Aug. 29.639	21 Z	−0 58	−27.55	+25.40	− 2.15	20	±2.2
270	1904, Sept. 11.680	25 Z	+0 53	−26.08	+24.14	− 1.94	20	2.5
291	1904, Nov. 14.488	27 K	+0.29	− 6.74	+ 3.53	− 3.21	19	2.4
303	1904, Dec. 22.358	25 K	−0 10	+11.92	−13.09	− 1.17	20	2.6
559	1906, Jan. 22.271	25 K	−0 13	+21.04	−22.81	− 1.77	20	2.2
600	1906, Mar. 7.239	27 K	+1 54	+21.97	−25.18	− 3.21	20	2.6
					Mean:	− 2.24		
			f Tauri					
	$\alpha\ 3^h\ 25^m.4,\ \delta+12°\ 36'$			Type XV ?, Mag. 5.11				
331	1905, Jan. 15.357	120 KZ	+1 15	+53.43	−26.80	+26.63	15	±1.6
842	1907, Jan. 27.307	(100)KZ	+0 50	+45.32	−28.96	+16.36	17	2.6
847	1907, Feb. 1.300	120 Z	+0 59	+45.40	−29.56	+15.84	16	3.1
					Velocity variable			
			γ Tauri					
	$\alpha\ 4^h\ 14^m.1,\ \delta+15°\ 23'$			Type XIV ?, Mag. 4.85				
854	1907, Feb. 7.327	102 Z	+1 11	+67.61	−28.76	+38.85	20	±3.0
857	1907, Feb. 9.282	100 Z	+0 15	+69.87	−28.98	+40.89	16	2.0
867	1907, Mar. 2.298	108 Z	+2 1	+68.98	−29.86	+39.12	18	2.4
					Mean:	+39.62		
			δ Tauri					
	$\alpha\ 4^h\ 17^m.2,\ \delta+17°\ 18'$			Type XV, Mag. 5.00				
346	1905, Jan. 26.376	105 Z	+1 34	+70.26	−26.31	+43.95	17	±2.0
815	1906, Dec. 21.460	120 Z	+1 11	+52.60	−12.28	+40.32	14	2.2
825	1907, Jan. 22.369	120 KZ	+1 6	+63.02	−25.03	+37.99	29	2.2
					Velocity variable ?			
			ε Tauri					
	$\alpha\ 4^h\ 22^m.8,\ \delta+18°\ 58'$			Type XV ?, Mag. 4.83				
344	1905, Jan. 23.381	115 Z	+1 24	+65.28	−25.06	+40.22	16	±1.2
572	1906, Jan. 24.355	115 Z	+0 49	+63.01	−25.23	+37.78	21	2.1
819	1906, Dec. 22.447	120 Z	+0 51	+52.22	−11.98	+40.24	19	2.2
					Mean:	+39.41		

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\ \Sigma v$

α Tauri

$\alpha\ 4^h\ 30^m.2,\ \delta + 16°\ 19'$ Type XVI, Mag. 3.94

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\ \Sigma v$
		min.		km	km	km		km
312	1905, Jan. 1.352	50 K	-0^h52^m	+72.34	−16.06	+56.28	15	±1.9
315	1905, Jan. 2.366	38 K	−0 27	+73.12	−16.53	+56.59	15	1.6
321	1905, Jan. 8.392	40 K	+0 34	+75.88	−19.17	+56.71	15	1.5
354	1905, Feb. 9.311	50 K	+0 43	+84.35	−28.49	+55.86	15	2.3
481	1905, Sept. 22.698	47 Z	+0 48	+28.86	+27.33	+56.19	20	1.9
516	1905, Dec. 1.501	50 Z	+0 39	+55.57	− 0.68	+54.89	20	1.9
769	1906, Sept. 24.691	57 Z	+0 44	+28.98	+27.01	+55.99	20	1.9
					Mean:	+56.07		

π³ Orionis

$\alpha\ 4^h\ 44^m.3,\ \delta + 6°\ 47'$ Type XIII*a*, Mag. 4.05

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\ \Sigma v$
334	1905, Jan. 20.370	90 Z	+0 35	+47.60	−22.15	+25.45	14	±2.2
561	1906, Jan. 22.412	80 K	+1 42	+49.90	−22.80	+27.10	16	3.5
811	1906, Dec. 18.457	100 Z	+0 29	+33.75	− 7.98	+25.77	12	2.9
					Mean:	+26.11		

ι Aurigae

$\alpha\ 4^h\ 50^m.4,\ \delta + 33°\ 0'$ Type XV, Mag. 4.87

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\ \Sigma v$
339	1905, Jan. 22.384	100 Z	+0 57	+40.72	−21.67	+19.05	13	±1.9
523	1905, Dec. 17.441	100 Z	−0 4	+24.61	− 5.32	+19.29	17	2.4
844	1907, Jan. 29.350	(90)KZ	+0 34	+43.46	−23.78	+19.68	22	1.8
					Mean:	+19.34		

ν Aurigae

$\alpha\ 5^h\ 44^m.6,\ \delta + 39°\ 7'$ Type XVI?, Mag. 5.17

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\ \Sigma v$
351	1905, Feb. 8.378	120 Z	+1 1	+34.57	−22.92	+11.65	13	±2.4
576	1906, Feb. 5.392	120 Z	+1 8	+31.59	−21.89	+ 9.70	15	1.9
871	1907, Mar. 3.335	120 Z	+1 28	+39.16	−27.91	+11.25	18	2.2
					Mean:	+10.87		

α Orionis

$\alpha\ 5^h\ 49^m.8,\ \delta + 7°\ 23'$ Type XVIII, Mag. bright

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\ \Sigma v$
356	1905, Feb. 9.407	60 Z	+1 41	+51.00	−23.11	+27.89	10	±2.8
367	1905, Mar. 1.309	62 Z	+0 39	+52.84	−27.54	+25.30	11	2.5
533	1905, Dec. 30.474	80 K	+1 35	+32.24	− 5.78	+26.46	18	2.7
591	1906, Mar. 4.317	60 Z	+1 1	+54.58	−27.94	+26.64	15	2.1
					Mean:	+26.57		

δ Aurigae

$\alpha\ 5^h\ 51^m.3,\ \delta + 54°\ 17'$ Type XV, Mag. 4.81

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\ \Sigma v$
874	1907, Mar. 4.323	95 Z	+1 8	+35.96	−24.78	+11.18	19	±1.6
882	1907, Mar. 7.307	90 Z	+0 57	+36.57	−25.09	+11.48	17	2.4
892	1907, Mar. 21.293	(88)KZ	+1 32	+35.85	−25.72	+10.13	23	1.7
					Mean:	+10.93		

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\Sigma v$

μ Geminorum

$\alpha\ 6^h\ 16^m.9,\ \delta + 22° 34'$ Type XVIII, Mag. 4.85

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\Sigma v$
		min.		km	km	km		km
530	1905, Dec. 26.503	100 K	$+0^h 35^m$	+57.99	− 0.42	+57.57	14	±2.5
573	1906, Jan. 24.447	100 Z	+1 8	+72.16	−15.06	+57.10	14	2.7
826	1907, Jan. 22.471	120 Z	+1 33	+70.40	−14.07	+56.33	16	2.8
					Mean:	+57.00		

ε Geminorum

$\alpha\ 6^h\ 37^m.8,\ \delta + 25° 14'$ Type XIV, Mag. 4.66

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\Sigma v$
370	1905, Mar. 8.366	90 Z	+1 40	+39.08	−27.90	+11.18:	11	±2.1
379	1905, Mar. 22.310	(130)KZ	+1 15	+38.15	−29.63	+ 8.52	15	1.5
588	1906, Feb. 28.376	(110)Z	+1 23	+34.86	−26.06	+ 8.80	18	2.5
833	1907, Jan. 23.468	105 Z	+1 12	+21.20	−12.29	+ 8.91	22	1.8
					Mean:	+ 9.35		

α Canis minoris

$\alpha\ 7^h\ 34^m.1,\ \delta + 5° 29'$ Type XII*a*, Mag. bright

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\Sigma v$
347	1905, Jan. 26.442	10 K	−0 7	+ 1.07	− 5.77	− 4.70	15	±0.8
359	1905, Feb. 13.352	(32)K	−1 6	+11.09	−14.13	− 3.04	14	1.8
381	1905, Apr. 13.294	18 K	+1 22	+25.27	−28.60	− 3.33	20	1.5
497	1905, Nov. 3.740	18 Z	+1 31	−31.76	+27.42	− 4.34	20	1.5
534	1905, Dec. 30.522	16 K	0 0	−11.15	+ 7.90	− 3.25	20	1.9
627	1906, Mar. 28.292	14 K	+0 16	+23.76	−27.23	− 3.47	20	2.1
794	1906, Nov. 10.684	20 Z	+0 35	−29.53	+26.34	− 3.19	20	1.4
					Mean:	− 3.62		

κ Geminorum

$\alpha\ 7^h\ 38^m.4,\ \delta + 24° 38'$ Type XIV, Mag. 4.62

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\Sigma v$
372	1905, Mar. 13.421	115 Z	+2 19	+48.44	−25.90	+22.54	14	±2.1
375	1905, Mar. 20.373	120 Z	+1 36	+49.58	−27.44	+22.14	16	1.8
602	1906, Mar. 7.363	120 Z	+0 31	+45.15	−24.00	+21.15	19	2.8
883	1907, Mar. 7.387	90 KZ	+1 5	+44.85	−23.96	+20.89	22	2.6
					Mean:	+21.68		

β Geminorum

$\alpha\ 7^h\ 39^m.2,\ \delta + 28° 16'$ Type XV, Mag. bright

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\Sigma v$
130	1904, Apr. 15.367	30 K	+3 11	+35.06	−29.61	+ 5.45	14	±1.5
287	1904, Oct. 30.687	(47)Z	−0 6	−24.81	+28.61	+ 3.80	15	1.3
368	1905, Mar 1.408	36 Z	+1 12	+26.16	−22.22	+ 3.94	16	1.1
368[1]	1905, Mar. 1.408	36 Z	+1 12	+26.49	−22.22	+ 4.27	20	1.4
382	1905, Apr. 13.330	39 K	+2 9	+33.42	−29.62	+ 3.80	20	1.9
385	1905, Apr. 14.323	42 K	+2 3	+34.66	−29.60	+ 5.06	20	1.7
494	1905, Nov. 3.668	34 Z	−0 18	−22.81	+28.04	+ 5.23	20	1.2
563	1906, Jan 22.501	30 K	+0 55	+10.90	− 5.20	+ 5.70	20	1.2
563[1]	1906, Jan. 22.501	30 K	+0 55	+10.46	− 5.20	+ 5.26	20	1.8
909	1907, Mar. 28.301	40 K	+0 23	+33.85	−28.49	+ 5.36	20	2.0
					Mean:	+ 4.79		

[1] Second measure with partially different lines.

β Cancri

α 8h 11m.1, δ +9° 30′ Type XV, Mag. 5.06

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
		min.		km	km	km		km
634	1906, Apr. 2.325	120 KZ	+0h46m	+51.95	−27.26	+24.69	12	±3.0
897	1907, Mar. 24.328	125 KZ	+0 14	+51.20	−25.23	+25.97	13	2.5
914	1907, Mar. 29.357	140 KZ	+1 15	+51.67	−26.47	+25.20	15	2.9
					Mean:	+25.29		

o Ursae majoris

α 8h 22m.0, δ +61° 3′ Type XIV, Mag. 4.66

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
855	1907, Feb. 7.418	90 KZ	−0 45	+29.81	− 9.97	+19.84	23	±2.6
860	1907, Feb. 9.407	100 KZ	−0 53	+31.61	−10.68	+20.93	16	2.6
886	1907, Mar. 9.312	(35) Z	−1 20	+40.52	−18.81	+21.71	16	2.8
900	1907, Mar. 26.306	80 KZ	−0 21	+42.45	−21.69	+20.76	28	2.4
					Mean:	+20.81		

ι Cancri

α 8h 40m.6, δ +29° 7′ Type XIV, Mag. 4.85

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
584	1906, Feb. 15.495	110 Z	+1 20	+28.74	−10.57	+18.17	14	±1.7
894	1907, Mar. 22.408	120 Z	+1 31	+40.61	−24.19	+16.42	13	2.1
910	1907, Mar. 28.369	120 Z	+0 59	+41.89	−25.72	+16.17	14	2.7
918	1907, Mar. 30.365	140 Z	+1 1	+43.74	−26.18	+17.56	14	2.4
					Mean:	+17.08		

ζ Hydrae

α 8h 50m.1, δ +6° 19′ Type XV, Mag. 4.42

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
365	1905, Feb. 28.425	(65)Z	+0 22	+37.29	−12.78	+24.51	16	±4.0
638	1906, Apr. 3.333	90 KZ	+0 23	+49.43	−25.05	+24.38	25	2.4
875	1907, Mar. 4.460	90 Z	+1 27	+38.03	−14.44	+23.59	20	2.2
					Mean:	+24.16		

40 *Lyncis*

α 9h 15m.0, δ +34° 49′ Type XVI, Mag. 4.98

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
613	1906, Mar. 17.435	120 Z	+1 17	+60.66	−20.18	+40.48	10	±4.3
639	1906, Apr. 3.412	120 Z	+1 52	+64.17	−25.04	+39.13	19	2.2
898	1907, Mar. 24.425	120 KZ	+1 30	+62.60	−22.36	+40.24	15	2.7
942	1907, Apr. 24.354	120 Z	+1 50	+65.56	−27.99	+37.57	19	2.4
					Mean:	+39.35		

α Hydrae

α 9h 22m.7, δ −8° 13′ Type XV, Mag. 4.16

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
136	1904, Apr. 20.342	66 K	+1 12	+21.95	−24.58	− 2.63	14	±1.8
608	1906, Mar. 14.436	90 Z	+0 59	+ 9.03	−12.45	− 3.42	22	2.6
621	1906, Mar. 26.377	90 Z	+0 21	+15.02	−17.15	− 2.13	23	2.2
901	1907, Mar. 26.380	80 K	+0 24	+15.18	−17.06	− 1.88	16	2.2
					Mean:	− 2.51		

θ Ursae majoris

α $9^h\,26^m.2$, δ + 52° 8′ Type XIII*a*, Mag. 4.14

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
		min.		km	km	km		km
376	1905, Mar. 20.466	60 Z	$+2^h\,4^m$	+35.46	−19.61	+15.85	15	±1.9
383	1905, Apr. 13.408	88 Z	+2 14	+39.97	−23.74	+16.23	13	2.1
603	1906, Mar. 7.452	92 Z	+0 51	+30.25	−15.72	+14.53	18	2.4
926	1907, Apr. 1.381	75 K	+0 47	+39.01	−21.99	+17.02	16	1.8

Mean: +15.91

ε Leonis

α $9^h\,40^m.2$, δ + 24° 14′ Type XIV *P*, Mag. 4.34

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
73*	1903, May 24.379	78 K	+3 59	+34.01	−28.50	+ 5.51	15	±2.8
73	1903, May 24.379	78 K	+3 59	+34.02	−28.50	+ 5.52	15	2.8
141	1904, Apr. 24.399	80 K	+2 32	+35.05	−28.19	+ 6.86	15	1.6
395	1905, Apr. 25.379	72 K	+2 7	+33.76	−28.26	+ 5.50	22	2.0
402	1905, May 15.349	(80)K	+2 41	+35.20	−29.11	+ 6.09	15	1.8

Mean: + 5.90

γ Leonis, maj. dpl.

α $10^h\,14^m.5$, δ + 20° 21′ Type XV, Mag. 3.72

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
54*	1903, May 4.421	60 K	+3 6	− 7.22	−28.25	−35.47	13	±2.6
54	1903, May 4.421	60 K	+3 6	− 6.58	−28.25	−34.83	15	2.6
148	1904, May 9.415	68 K	+3 20	− 4.88	−28.87	−33.75	15	1.8
397	1905, May 3.349	60 Z	+1 21	− 6.59	−28.07	−34.66	15	1.0
929	1907, Apr. 2.422	70 K	+1 2	−15.15	−20.04	−35.19	30	2.1
948	1907, May 11.344	75 K	+1 43	− 5.81	−28.88	−34.69	20	2.3

Mean: −34.77

μ Ursae majoris

α $10^h\,16^m.4$, δ + 42° 0′ Type XVI, Mag. 4.88

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
137	1904, Apr. 20.451	118 Z	+2 54	+11.99	−24.43	−12.44	15	±1.6
155	1904, May 16.376	90 KZ	+2 50	+16.39	−25.79	− 9.40	14	1.7
679	1906, May 3.377	(120)Z	+1 57	+11.46	−25.65	−14.19	14	3.0
680	1906, May 8.359	100 Z	+1 51	+10.95	−25.84	−14.89	13	3.4
681	1906, May 11.358	(120)Z	+2 1	+ 7.27:	−25.87	−18.60:	9	4.4

Velocity variable

46 *Leonis minoris*

α $10^h\,47^m.7$, δ + 34° 45′ Type XV, Mag. 4.95

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
635	1906, Apr. 2.425	120 KZ	+0 33	+36.99	−18.02	+18.97	18	±3.2
906	1907, Mar. 27.477	120 Z	+1 23	+32.90	−15.84	+17.06	21	1.9
915	1907, Mar. 29.471	135 Z	+1 22	+34.76	−16.57	+18.19	21	2.0
940	1907, Apr. 22.378	120 Z	+0 43	+41.16	−23.54	+17.62	22	2.4

Mean: +17.96

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma r^2$
			α Ursae majoris					
		α 10h 57m.6, δ+62° 18′			Type XV, Mag. 4.10			
		min.		km	km	km		km
95*	1903, June 27.391	60 K	$+5^h12^m$	+ 4.93	−12.03	− 7.10	13	±1.4
95	1903, June 27.391	60K	+5 12	+ 4.65	−12.03	− 7.38	15	1.6
135	1904, Apr. 19.458	45 KZ	+2 20	+ 9.27	−18.57	− 9.30	15	2.9
158	1904, May 19.356	37 K	+1 51	+10.43	−18.53	− 8.10	16	2.0
399	1905, May 11.376	60 Z	+1 47	+13.04	−19.02	− 5.98	16	1.3
670	1906, Apr. 13.413	60 K	+0 49	+11.48	−17.87	− 6.39	17	2.0
					Mean:	− 7.38		
			ψ Ursae majoris					
		α 11h 4m.0, δ+45° 3′			Type XV, Mag. 4.59			
131	1904, Apr. 15.501	105 KZ	+3 1	+18.63	−20.42	− 1.79	15	±1.9
146	1904, May 7.420	70 K	+2 30	+20.59	−23.65	− 3.06	15	1.5
401	1905, May 12.374	(110)Z	+1 42	+21.80	−23.89	− 2.09	15	2.4
649	1906, Apr. 6.471	110 Z	+1 40	+15.39	−18.01	− 2.62	22	3.0
					Mean:	− 2.39		
			ν Ursae majoris					
		α 11h 13m.1, δ+33° 38′			Type XVI ?, Mag. 5.15			
160	1904, May 20.389	124 KZ	+2 27	+18.35	−26.37	− 8.02	11	±1.8
163	1904, June 4.382	105 KZ	+3 16	+19.92	−26.24	− 6.32	14	2.0
938	1907, Apr. 10.467	120 Z	+1 40	+11.86	−18.50	− 6.64	13	1.9
946	1907, May 10.364	120 Z	+1 10	+16.47	−25.36	− 8.89	18	2.8
					Mean:	− 7.47		
			χ Ursae majoris					
		α 11h 40m.8, δ+48° 20′			Type XV, Mag. 4.92			
156	1904, May 16.474	114 KZ	+3 46	+16.29	−22.00	− 5.71	15	±3.3
159	1904, May 19.449	106 Z	+3 22	+14.05	−22.09	− 8.04	13	2.4
687	1906, May 29.381	105 Z	+2 22	+13.69	−22.02	− 8.33	15	3.1
					Mean:	− 7.36		
			β Virginis					
		α 11h 45m.5, δ+2° 20′			Type XIIIa, Mag. 4.40			
622	1906, Mar. 26.491	120 Z	+0 42	+ 9.64	− 4.54	+ 5.10	26	±3.2
660	1906, Apr. 9.450	120 Z	+0 39	+16.21	−11.36	+ 4.85	15	2.5
666	1906, Apr. 11.444	105 Z	+0 38	+16.69	−12.29	+ 4.40	15	2.4
684	1906, May 28.371	95 Z	+1 59	+32.99	−27.77	+ 5.22	20	2.5
					Mean:	+ 4.89		
			o Virginis					
		α 12h 0m.1, δ+9° 17′			Type XIV, Mag. 5.03			
308	1905, May 3.438	(130)Z	+1 43	− 6.17	−20.97	−27.14	15	±2.9
674	1906, Apr. 15.458	(135)K	+0 59	−16.11	−13.71	−29.82	13	2.5
913	1907, Apr. 24.445	120 Z	+1 16	−10.01	−17.40	−27.41	14	4.2
					Mean:	−28.12		

ε *Virginis*

α 12h 57m.2, δ + 11° 30′ Type XV, Mag. 4.72

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
		min.		km	km	km		km
80*	1903, May 29.385	70 K	$+1^h 10^m$	+11.50	−24.02	−12.52	15	±2.4
80	1903, May 29.385	70 K	+1 10	+12.86	−24.02	−11.16	15	2.5
143	1904, Apr. 25.436	65 KZ	+0 13	+ 0.95	−12.36	−11.41	16	1.3
150	1904, May 15.377	65 K	+0 6	+ 5.15	−20.08	−14.93	16	2.3
387	1905, Apr. 14.481	90 Z	+0 32	− 5.36	− 7.30	−12.66	16	1.5
535	1905, Dec. 30.754	65 K	+0 11	−41.90	+29.05	−12.85	32	2.1
682	1906, May 23.394	100 Z	+1 1	+10.25	−22.47	−12.22	22	2.9
689	1906, June 6.381	80 Z	+1 37	+13.34	−25.87	−12.53	22	2.0

Mean: −12.54

η *Boötis*

α 13h 49m.9, δ + 18° 54′ Type XIV, Mag. 3.79

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
72*	1903, May 23.403	60 K	+0 20	+24.86	−17.70	+ 7.16	14	±1.8
72	1903, May 23.403	60 K	+0 20	+25.69	−17.70	+ 7.99	14	1.7
142	1904, Apr. 24.501	75 KZ	+0 50	+ 4.84:	− 7.02	− 2.18:	14	2.1
147	1904, May 7.480	(60)K	+1 10	+ 8.10	−12.35	− 4.25	16	1.8
405	1905, May 28.407	85 Z	+0 47	+15.98	−19.39	− 3.41	16	2.3
568	1906, Jan. 23.735	60 K	+0 26	−19.51	+25.73	+ 6.22	26	1.7
691	1906, June 7.371	65 Z	+0 33	+25.83	−21.90	+ 3.93	26	2.6

Velocity variable

α *Boötis*

α 14h 11m.1, δ + 19° 42′ Type XV, Mag. bright

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
301	1904, Dec. 21.797	21 K	−0 35	−28.43	+24.03	− 4.40	20	±1.3
427	1905, July 7.349	20 K	+1 40	+21.20	−25.02	− 3.82	20	1.9
570	1906, Jan. 23.787	19 K	+1 20	−29.52	+25.46	− 4.06	20	1.4
623	1906, Mar. 27.597	20 K	+0 53	−12.03	+ 7.58	− 4.45	20	2.0
676	1906, Apr. 15.556	23 K	+1 10	− 2.51	− 0.65	− 3.16	20	1.9
964	1907, July 21.345	26 K	+2 27	+21.79	−25.22	− 3.43	20	1.3

Mean: − 3.89

ρ *Boötis*

α 14h 27m.5, δ + 30° 49′ Type XV, Mag. 4.98

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
406	1905, May 29.481	100 Z	+2 0	+ 4.13	−15.68	−11.55	15	±2.0
416	1905, June 20.442	120 Z	+2 29	+ 8.48	−20.08	−11.60	11	2.8
690	1906, June 6.460	105 Z	+2 0	+ 6.08	−17.50	−11.42	16	1.3
945	1907, May 9.476	120 Z	+0 31	− 2.84	− 9.53	−12.37	15	2.2

Mean: −11.74

ε Boötis, maj. dpl.

α 14^h 40^m.6, δ +27° 30′ Type XV, Mag. bright

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
		min.		km	km	km		km
82*	1903, May 31.455	60 K	+1^{h}16^m	− 0.86	−15.00	−15.86	14	±3.3
82	1903, May 31.455	60 K	+1 16	+ 0.49	−15.00	−14.51	14	2.2
144	1904, Apr. 25.524	60 KZ	+0 35	− 8.25:	− 3.06	−11.31:	15	1.6
208	1904, June 26.408	62 K	+1 53	+ 5.82	−20.72	−14.90	16	1.5
418	1905, June 22.415	60 K	+1 46	+ 4.34	−20.06	−15.72	14	2.0
625	1906, Mar. 27.661	75 K	+1 56	−25.72	+ 8.04	−17.68	28	1.8

Velocity variable?

β Ursae minoris

α 14^h 51^m.0, δ +74° 34′ Type XVI, Mag. 4.09

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
105*	1903, July 2.492	75 K	+4 5	+22.27	− 4.62	+17.65	14	±2.9
105	1903, July 2.492	75 K	+4 5	+23.17	− 4.62	+18.55	14	1.7
183	1904, June 13.394	42 KZ	+0 31	+24.14	− 6.57	+17.57	15	2.6
186	1904, June 14.386	60 K	+0 24	+26.29	− 6.48	+19.81	15	1.7
247	1904, Aug. 2.393	63 K	+3 47	+19.50	− 2.81	+16.69	14	2.3
944	1907, May 7.430	(60)Z	−1 6	+28.36	− 8.60	+19.76	17	2.4

Mean: +18.34

β Boötis

α 14^h 58^m.2, δ +40° 47′ Type XIV, Mag. 4.56

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
71*	1903, May 22.516	90 K	+1 51	−10.42	−10.49	−20.91	14	±2.3
71	1903, May 22.516	90 K	+1 51	− 9.18	−10.49	−19.67	11	2.9
109*	1903, July 15.447	90 K	+3 44	− 2.21	−17.33	−19.54	14	2.6
109	1903, July 15.447	90 K	+3 44	− 1.69	−17.33	−19.02	12	3.0
692	1906, June 7.442	95 Z	+1 8	− 5.89	−13.74	−19.63	17	3.6
947	1907, May 10.453	95 Z	−0 27	−10.42	− 7.37	−17.79	17	2.4

Mean: −19.43

δ Boötis

α 15^h 11^m.5, δ +33° 42′ Type XV, Mag. 4.72

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
74*	1903, May 24.473	80 K	+0 43	− 2.97	− 9.74	−12.71	14	±2.0
74	1903, May 24.473	80 K	+0 43	− 2.64	− 9.74	−12.38	13	3.3
149	1904, May 13.485	(120)Z	+0 18	− 5.99:	− 6.69	−12.68:	15	2.6
949	1907, May 11.451	110 Z	−0 40	− 3.40	− 5.76	− 9.16	18	2.6

Mean: −11.73

ι Draconis

α 15^h 22^m.7, δ +59° 19′ Type XV, Mag. 5.02

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
196	1904, June 20.405	100 KZ	+0 42	− 1.01	− 9.48	−10.49	17	±3.2
412	1905, June 3.370	50 Z	−1 16	− 0.13	− 8.79	− 8.92	15	1.9
429	1905, July 7.433	85 Z	+2 28	− 1.47	− 9.38	−10.85	15	1.3
952	1907, May 25.392	(85)Z	−1 22	− 0.27	− 8.13	− 8.40	18	2.4

Mean: − 9.66

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\Sigma v$

α *Serpentis*

α 15h 39m.3, δ +6° 44′ Type XV, Mag. 4.23

Plate No.	Date	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\Sigma v$
		min.		km	km	km		km
78*	1903, May 26.454	60 K	−0h 4m	+ 9.74	− 6.04	+ 3.70	14	±2.0
78	1903, May 26.454	60 K	−0 4	+11.31	− 6.04	+ 5.27	13	1.5
81*	1903, May 30.473	60 K	+0 40	+13.59	− 7.84	+ 5.75	15	1.7
81	1903, May 30.473	60 K	+0 40	+12.12	− 7.84	+ 4.28	14	1.5
213	1904, June 29.410	73 K	+1 9	+23.95	−19.35	+ 4.60	16	2.1
954	1907, June 11.450	75 K	+0 53	+17.39	−12.77	+ 4.62	16	1.9

Mean: + 4.70

γ *Serpentis*

α 15h 51m.8, δ +16° 0′ Type XIIIa, Mag. 4.54

Plate No.	Date	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\Sigma v$
415	1905, June 19.458	(120)Z	+1 26	+22.21	−14.25	+ 7.96	15	±1.9
710	1906, July 16.410	120 KZ	+2 1	+27.76	−21.29	+ 6.47	18	2.1
713	1906, July 17.398	120 KZ	+1 48	+28.34	−21.46	+ 6.88	19	1.7

Mean: + 7.10

δ *Ophiuchi*

α 16h 9m.1, δ −3° 26′ Type XVII, Mag. 4.53

Plate No.	Date	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\Sigma v$
956	1907, June 27.440	100 K	+1 12	− 1.33	−15.71	−17.04	17	±2.7
958	1907, July 8.410	125 Z	+1 19	+ 1.51	−19.73	−18.22	13	3.0
960	1907, July 19.369	120 Z	+0 56	+ 5.06	−23.06	−18.00	20	2.3
962	1907, July 20.371	120 Z	+1 4	+ 8.27:	−23.33	−15.06:	10	2.2

Mean: −17.08

η *Draconis*

α 16h 22m.6, δ +61° 44′ Type XIV?, Mag. bright

Plate No.	Date	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\Sigma v$
411	1905, May 31.453	60 Z	−0 27	− 7.68	− 4.86	−12.54	16	±1.6
425	1905, July 6.456	65 Z	+1 59	− 7.54	− 5.93	−13.47	16	2.0
448	1905, July 29.385	(90)K	+1 47	− 6.07	− 5.45	−11.52	17	2.4
955	1907, June 27.367	70 K	−0 48	− 8.08	− 5.77	−13.85	24	1.6

Mean: −12.84

β *Herculis*

α 16h 25m.9, δ +21° 42′ Type XV, Mag. 4.17

Plate No.	Date	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\Sigma v$
93*	1903, June 26.383	60 K	−0 30	− 0.76	−12.05	−12.81	14	±2.5
93	1903, June 26.383	60 K	−0 30	+ 0.45	−12.05	−11.60	16	2.5
164	1904, June 4.463	66 KZ	+0 1	−21.18	− 5.09	−26.27	16	2.2
197	1904, June 20.490	70 Z	+1 41	−13.57	−10.62	−24.19	15	2.2
217	1904, July 4.435	67 K	+1 19	− 6.74	−14.68	−21.42	15	2.0
243	1904, July 23.373	40 K	+1 4	+ 1.61	−18.93	−17.32	16	1.9

Velocity variable

ζ Herculis

α 16h 37m.5, δ +31° 47′ Type XIV, Mag. 3.93

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/n\,\Sigma v$
		min.		km	km	km		km
66*	1903, May 21.491	60 K	−0h 29m	−73.59	+ 0.36	−73.23	14	±2.2
66	1903, May 21.491	60 K	−0 29	−73.44	+ 0.36	−73.08	16	1.5
83*	1903, May 31.513	60 K	+0 42	−72.43	− 2.71	−75.14	13	1.7
83	1903, May 31.513	60 K	+0 42	−72.12	− 2.71	−74.83	12	2.3
184	1904, June 13.457	60 KZ	+0 15	−65.63	− 6.60	−72.23	16	1.5
238	1904, July 19.378	60 K	+0 44	−56.99	−14.76	−71.75	16	1.9
705	1906, July 2.459	100 Z	+1 31	−60.19	−11.37	−71.56	31	2.2

Velocity variable

η Herculis

α 16h 39m.5, δ +39° 7′ Type XV, Mag. 4.65

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/n\,\Sigma v$
233	1904, July 15.407	120 KZ	+1 8	+23.04	−12.05	+10.99	14	±2.1
236	1904, July 18.401	102 Z	+1 11	+21.35	−12.45	+ 8.90	13	2.2
443	1905, July 26.399	105 Z	+1 38	+25.22	−13.37	+11.85	28	2.8
967	1907, July 24.402	120 Z	+1 33	+23.71	−13.10	+10 61	20	2.6

Mean: +10.59

κ Ophiuchi

α 16h 52m.9, δ +9° 32′ Type XV, Mag. 4.56

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/n\,\Sigma v$
187	1904, June 14.470	95 KZ	+0 23	−49.95:	− 5.47	−55.42:	15	±2.7
202	1904, June 21.487	95 KZ	+1 15	−43.89	− 8.36	−52.25	15	1.5
230	1904, July 12.414	104 KZ	+0 53	−37.58	−15.96	−53.54	13	1.7
453	1905, Aug. 3.395	100 Z	+1 51	−31.65	−21.87	−53.52	17	1.9

Mean: −53.68

π Herculis

α 17h 11m.6, δ +36° 55′ Type XV, Mag. 4.98

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/n\,\Sigma v$
204	1904, June 23.481	96 Z	+0 55	−16.52	− 5.40	−21.92	9	±2.7
211	1904, June 27.484	(100)K	+1 15	−17.20	− 6.35	−23.55	13	3.0
249	1904, Aug. 3.383	93 K	+1 15	−10.83	−13.05	−23.88	14	1.9
959	1907, July 14.436	(110)Z	+1 10	−13.32	− 9.74	−23.06	17	2.8

Mean: −23.10

β Draconis

α 17h 28m.2, δ +52° 23′ Type XIV, Mag. 4.19

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/n\,\Sigma v$
167	1904, June 6.451	58 KZ	−1 12	−19.62	− 0.56	−20.18	14	±2.3
170	1904, June 7.433	90 KZ	−1 34	−22.35	− 0.67	−23.02	13	2.1
185	1904, June 13.522	62 KZ	+0 59	−18.91	− 1.55	−20.46	15	1.9
244	1904, July 29.390	64 K	+0 49	−13.30	− 6.22	−19.52	16	1.3
965	1907, July 21.453	68 K	+1 46	−14.23	− 5.58	−19.81	18	2.3

Mean: −20.60

β Ophiuchi

α 17h 38m.5, δ +4° 36′ Type XV, Mag. 4.19

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\ \varepsilon_v$
		min.		km	km	km		km
86*	1903, June 15.491	75 K	+0h 10m	−12.00	+ 0.27	−11.73	14	±2.2
86	1903, June 15.491	75 K	+0 10	−11.67	+ 0.27	−11.40	14	2.3
96*	1903, June 27.500	75 K	+1 10	− 4.11	− 5.04	− 9.15	13	2.6
96	1903, June 27.500	75 K	+1 10	− 4.47	− 5.04	− 9.51	14	2.0
165	1904, June 4.531	90 KZ	+0 26	−15.70	+ 4.69	−11.01	15	2.0
240	1904, July 21.392	80 K	+0 12	+ 5.15	−14.83	− 9.68	15	1.5

Mean: −10.41

μ Herculis

α 17h 42m.5, δ +27° 47′ Type XIV, Mag. 4.39

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\ \varepsilon_v$
239	1904, July 19.446	93 Z	+1 18	− 4.51	−10.13	−14.64	16	±2.0
242	1904, July 22.412	94 Z	+0 41	− 3.67	−10.86	−14.53	16	1.8
439	1905, July 20.430	(65)Z	+0 57	− 2.67	−10.30	−12.97	17	2.6
450	1905, July 31.405	90 Z	+1 4	− 2.89	−12.96	−15.85	15	1.7

Mean: −14.50

ξ Draconis

α 17h 51m.8, δ +56° 53′ Type XV, Mag. 5.34

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\ \varepsilon_v$
423	1905, July 3.489	120 Z	+1 5	−24.08	− 1.56	−25.64	12	±1.5
716	1906, July 23.430	120 Z	+0 58	−22.00	− 3.01	−25.01	17	2.9
718	1906, July 25.363	115 K	−0 31	−23.70	− 3.08	−26.78	23	1.9

Mean: −25.81

ξ Herculis

α 17h 53m.9, δ +29° 16′ Type XV, Mag. 4.79

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\ \varepsilon_v$
420	1905, June 23.501	(115)Z	+0 41	+ 2.24	− 1.22	+ 1.02	14	±2.8
433	1905, July 8.503	110 Z	+1 43	+ 4.84	− 5.69	− 0.85	13	1.7
724	1906, July 30.398	120 Z	+0 37	+10.58	−11.29	− 0.71	27	2.1
961	1907, July 19.465	110 Z	+1 29	+ 8.77	− 8.55	+ 0.22	19	1.8

Mean: − 0.08

γ Draconis

α 17h 54m.3, δ +51° 30′ Type XVI, Mag. 4.45

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\ \varepsilon_v$
85*	1903, June 11.494	85 K	−0 17	−28.04	+ 0.95	−27.09	14	±2.2
85	1903, June 11.494	85 K	−0 17	−28.06	+ 0.95	−27.11	13	2.1
168	1904, Jnne 6.503	75 KZ	−0 21	−27.69	+ 1.49	−26.20	15	1.9
171	1904, June 7.497	85 KZ	−0 26	−26.54	+ 1.38	−25.16	16	1.0
245	1904, July 29.445	73 K	+1 43	−21.60	− 4.99	−26.59	15	2.3

Mean: −26.43

η Serpentis

α 18h 16m.1, δ − 2° 56′ Type XV, Mag. 4.62

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
		min.		km	km	km		km
220	1904, July 6.468	115 Z	+0h 24m	+16.94	− 4.83	+12.11	11	±2.6
228	1904, July 11.460	125 Z	+0 32	+18.28	− 7.10	+11.18	13	1.8
747	1906, Aug. 28.346	115 Z	+0 56	+33.54	−24.21	+ 9.33	14	3.1
963	1907, July 20.468	120 Z	+1 16	+21.34	−10.78	+10.56	12	2.1

Mean: +10.80

χ Draconis

α 18h 22m.9, δ + 72° 41′ Type XIII*a*, Mag. 4.24

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
726	1906, Aug. 2.358	90 Z	−0 38	+13.49	+ 2.71	+16.20	16	±1.8
728	1906, Aug. 6.361	90 Z	−0 17	+12.55	+ 2.84	+15.39	17	1.7
731	1906, Aug. 7.343	80 Z	−0 38	+13.49	+ 2.86	+16.35	21	2.3
772	1906, Sept. 26.285	(80)Z	+1 14	+29.76	+ 3.12	+32.88	14	2.9
974	1907, Aug. 25.362	90 Z	+0 59	+33.43	+ 3.20	+36.63	15	2.1

Velocity variable

δ Draconis

α 19h 12m.5, δ + 67° 29′ Type XV, Mag. 4.69

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
232	1904, July 14.449	92 Z	−0 29	+21.33	+ 3.62	+24.95	15	±1.7
234	1904, July 16.413	83 Z	−1 13	+21.35	+ 3.63	+24.98	15	2.6
426	1905, July 6.517	60 Z	+0 37	+21.50	+ 3.61	+25.11	15	2.1
764	1906, Sept. 12.330	80 Z	+0 34	+24.09	+ 1.58	+25.67	20	2.1

Mean: +25.18

κ Cygni

α 19h 14m.8, δ + 53° 11′ Type XV, Mag. 4.94

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
441	1905, July 21.426	115 Z	−0 37	−29.66	+ 2.13	−27.53	16	±1.2
479	1905, Sept. 22.354	105 Z	+1 47	−20.95	− 6.07	−27.02	16	1.5
733	1906, Aug. 8.378	115 Z	−0 37	−27.61	− 0.29	−27.90	26	2.2
786	1906, Oct. 22.261	120 Z	+1 31	−20.42	− 8.15	−28.57	19	2.0

Mean: −27.76

β Cygni, maj. dpl.

α 19h 26m.7, δ + 27° 45′ Type XV, Mag. 4.31

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
103*	1903, July 1.570	90 K	+1 18	−29.48	+ 6.78	−22.70	13	±1.7
103	1903, July 1.570	90 K	+1 18	−29.79	+ 6.78	−23.01	14	1.8
224	1904, July 8.465	82 Z	−0 44	−25.05:	+ 4.55	−20.50:	14	3.8
226	1904, July 10.466	87 Z	−0 35	−27.33	+ 3.91	−23.42	14	1.8
757	1906, Sept. 3.378	85 K	+0 54	−11.25	−12.84	−24.09	15	2.0

Mean: −22.74

γ *Aquilae*

α $19^h\,41^m\!.5$, $\delta + 10°\,22'$ Type XV, Mag. 4.66

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
		min.		km	km	km		km
97*	1903, June 28.500	75 K	-0^h50^m	−10.17	+10.08	− 0.09	13	±2.2
97	1903, June 28.500	75 K	−0 50	− 9.91	+10.08	+ 0.17	11	2.5
231	1904, July 12.519	84 Z	+0 36	− 3.85	+ 3.99	+ 0.14	13	2.5
472	1905, Sept. 17.354	90 Z	+1 0	+20.80	−20.95	− 0.15	13	1.9
483	1905, Sept. 28.329	(75)Z	+1 8	+23.14	−23.33	− 0.19	16	2.4
759	1906, Sept. 4.365	100 Z	+0 23	+16.00	−17.10	− 1.10	15	2.3
781	1906, Oct. 10.282	95 Z	+0 46	+22.29	−24.98	− 2.69	15	2.5

Mean: − 0.56

ϵ *Draconis*

α $19^h\,48^m\!.5$, $\delta + 70°\,1'$ Type XIV ?, Mag. 4.95

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
430	1905, July 7.516	95 Z	+0 2	− 0.44	+ 5.13	+ 4.69	13	±2.3
719	1906, July 25.460	(110)Z	−0 7	− 2.23	+ 5.34	+ 3.11	18	2.6
723	1906, July 29.442	120 Z	−0 18	− 1.75	+ 5.33	+ 3.58	18	2.6
755	1906, Sept. 1.330	120 Z	−0 44	+ 0.10	+ 4.27	+ 4.37	24	2.2

Mean: + 3.94

β *Aquilae*

α $19^h\,50^m\!.4$, $\delta + 6°\,10'$ Type XV, Mag. 4.83

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
444	1905, July 26.491	100 Z	+0 40	−36.10	− 1.20	−37.30	15	±2.2
462	1905, Aug. 17.388	120 Z	−0 21	−26.86	−10.58	−37.44	17	2.2
714	1906, July 17.511	120 Z	+0 32	−43.15	+ 2.89	−40.26	17	2.1
985	1907, Sept. 19.360	125 Z	+1 6	−17.07	−21.91	−38.98	16	2.1

Mean: —38.50

η *Cygni*

α $19^h\,52^m\!.6$, $\delta + 34°\,49'$ Type XV, Mag. 5.06

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
458	1905, Aug. 13.407	120 Z	−0 12	−22.38	− 2.82	−25.20	18	±1.7
488	1905, Oct. 16.307	118 Z	+1 36	− 9.17	−16.70	−25.87	16	2.0
732	1906, Aug. 7.458	120 Z	+0 36	−24.99	− 1.06	−26.05	14	3.1
741	1906, Aug. 22.351	120 Z	−0 59	−18.77	− 5.21	−23.98	20	3.0

Mean: −25.27

31 Cygni

α $20^h\,10^m\!.5$, $\delta + 44°\,26'$ Type XV, Mag. 5.16

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
460	1905, Aug. 14.383	120 Z	−1 1	− 3.24	+ 1.12	− 2.12	16	±2.0
711	1906, July 16.546	(90)Z	+0 59	−16.02:	+ 7.04	− 8.98:	9	3.6
717	1906, July 23.535	115 Z	+1 10	−18.49:	+ 5.69	−12.80:	10	1.6
725	1906, July 30.521	120 Z	+1 18	−16.24	+ 4.28	−11.96	18	2.9

Velocity variable

Plate No.	Date Greenwich M. T.	Expo-sure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
			γ Cygni					
	α $20^h\ 18^m.6$, δ + 39° 56′			Type XIII*c*, Mag. 3.16				
		min.		km	km	km		km
92*	1903, June 25.508	75 K	$-1^h 27^m$	−20.30	+12.34	− 7.96	13	±4.1
92	1903, June 25.508	75 K	−1 27	−19.52	+12.34	− 7.18	14	2.3
235	1904, July 16.485	53 K	−0 35	−12.44	+ 7.82	− 4.62	15	2.2
246	1904, July 29.506	48 K	+0 47	−10.44	+ 4.53	− 5.91	16	3.4
248	1904, Aug. 2.481	35 K	+0 25	− 8.69	+ 3.52	− 5.17	16	3.0
449	1905, July 29.507	(48) K	+0 46	−10.79	+ 4.60	− 6.19	15	3.3
761	1906, Sept. 8.384	55 K	+0 30	− 0.87	− 6.19	− 7.06	27	3.1
					Mean:	− 6.30		
			ε Cygni					
	α $20^h\ 42^m.2$, δ + 33° 36′			Type XV, Mag. 3.85				
237	1904, July 18.487	53 K	−0 48	−24.13	+ 9.66	−14.47	16	±1.4
274	1904, Oct. 14.411	52 K	+3 10	+ 2.11	−16.21	−14.10	28	2.0
284	1904, Oct. 29.249	52 K	+0 15	+ 3.10	−18.38	−15.28	16	1.0
482	1905, Sept. 24.365	(60)K	+0 44	− 2.50	−11.30	−13.80	26	1.6
498	1905, Nov. 6.250	(60)K	+0 47	+ 6.89	−19.16	−12.27	29	1.9
767	1906, Sept. 23.406	55 K	+1 38	+ 4.88	−11.03	− 6.15	26	2.1
					Velocity variable			
			η Cephei					
	α $20^h\ 43^m.3$, δ + 61° 27′			Type XV, Mag. 4.88				
263	1904, Aug. 29.371	100 Z	−0 50	−90.41	+ 4.15	−86.26	16	±1.2
273	1904, Oct. 14.322	93 KZ	+1 1	−82.27	− 3.02	−85.29	15	1.7
275	1904, Oct. 15.262	87 Z	−0 21	−82.89	− 3.12	−86.01	15	1.1
752	1906, Aug. 30.374	92 Z	−0 44	−90.44	+ 4.08	−86.36	18	1.8
					Mean:	−85.98		
			ζ Cygni					
	α $21^h\ 8^m.7$, δ + 29° 49′			Type XV, Mag. 4.42				
276	1904, Oct. 16.260	92 Z	−0 46	+31.37	−17.01	+14.36	15	±1.5
286	1904, Oct. 30.317	72 K	+1 30	+34.61	−19.92	+14.69	16	1.7
467	1905, Aug. 24.399	100 Z	−0 56	+14.19	+ 0.06	+14.25	19	1.3
758	1906, Sept. 3.456	90 Z	+1 4	+19.34:	− 3.64	+15.70:	20	4.3
					Velocity variable			
			β Aquarii					
	α $21^h\ 26^m.3$, δ − 6° 1′			Type XIV, Mag. 4.20				
282	1904, Oct. 28.280	100 Z	+0 13	+34.64	−28.47	+ 6.17	14	±1.0
292	1904, Nov. 15.243	103 Z	+0 29	+36.10	−29.78	+ 6.32	15	1.5
754	1906, Aug. 31.453	100 Z	+0 30	+15.74	− 8.23	+ 7.51	25	2.4
771	1906, Sept. 25.384	100 KZ	+0 29	+25.80	−19.20	+ 6.60	22	2.9
					Mean:	+ 6.65		

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
				λ Andromedae				
	α 23h 32m.7, δ +45° 55′				Type XV, Mag. 5.00			
		min.		km	km	km		km
780	1906, Oct. 9.398	120 Z	−0h 22m	+ 7.66	+ 0.16	+ 7.82	18	±3.0
792	1906, Nov. 10.282	120 Z	−1 3	+25.08	−11.21	+13.87	20	2.5
800	1906, Nov. 20.255	120 Z	−1 2	+20.58	−14.27	+ 6.31	19	1.9
816	1906, Dec. 22.248	120 Z	+0 55	+34.87	−20.95	+13.92	20	2.4
					Velocity variable			
				γ Cephei				
	α 23h 35m.2, δ +77° 4′				Type XV, Mag. 4.87			
506	1905, Nov. 28.247	100 Z	−0 44	−39.57	− 1.69	−41.26	23	±1.6
509	1905, Nov. 30.223	100 Z	−1 10	−39.48	− 2.13	−41.61	16	1.1
766	1906, Sept. 13.480	100 Z	−0 8	−54.28	+11.72	−42.56	16	2.5
782	1906, Oct. 10.387	95 Z	−0 34	−49.29	+ 8.42	−40.87	16	1.9
1002	1907, Oct. 4.407	90 Z	−0 38	−51.39	+ 9.40	−41.99	19	1.7
					Mean:	−41.66		

Among these 99 stars there are 15 with previously known variable velocities; there are three others:

δ Tauri, *ε Boötis*, and *μ Pegasi*

of which it is suspected that their velocities vary.

For the remaining 81 stars the mean values for the plates are given above, no plate that was measured having been omitted. A few plates which were taken under especially unfavorable circumstances are designated as uncertain by the symbol : ; but these plates enter with their full value into the mean. The total number of the plates of these 81 stars is 355, and the sum of the squares of the deviations of the separate plates from the mean is computed to be 249.75. From this follows:

$$\text{Probable error of a plate} = 0.6745\sqrt{\frac{249.75}{274}} = \pm 0.64 \text{ km.}$$

This probable error will presumably be somewhat diminished in the definitive discussion, when the relative corrections for the wave-lengths of the star lines, provisionally taken from Rowland's solar lines, are computed. Since the whole series contains in round numbers 7500 complete measures of about 44 different stellar lines, it will be possible to obtain a very sharp determination of the relative wave-lengths of these lines and at the same time of their dependence

on the type. It is to be expected, however, that the above mean of the radial velocities will not be very much altered by these relative corrections to the lines, inasmuch as the mean for each separate star depends upon a large number of different lines.

Perhaps of somewhat more considerable amount will be found the constant correction which is further to be applied to the observed radial velocities, due in the first place to the absolute errors of the wave-lengths for the *Fe* lines and the star lines taken from Kayser and from Rowland; and in the second place to the combined effect of the instrumental and personal errors which come into play in making and in measuring the spectrograms. It is customary to determine this constant correction by control plates of the sun, moon, or larger planets, and to compare the observed radial velocities with those given precisely by theory. I regard this control as by no means valid, inasmuch as the light used in such cases proceeds from a surface and uniformly illuminates the entire area of the collimating lens; while the star's light, with the very small slit-width necessary, illuminates only a diametral strip with a maximum of intensity along the middle line. The path of the rays is therefore decidedly different in the two cases. ***An exact test of the observed radial velocities of stars can in my opinion be obtained only by the observation of a source of light of precisely known radial velocity and as similar as possible to a star, under conditions as closely as possible the same in the observation of the star.***

For instruments of great light-power, with which faint stars can be spectrographically observed, the brightest of the minor planets are especially adapted for this purpose, and perhaps also the satellites of *Jupiter*. Otherwise such a starlike source of light could be most readily produced artificially by a heliotrope set at a sufficiently great distance, as such are used in geodetic triangulations. This could not be attempted at Bonn readily, as the photographic refractor does not permit a view toward distant mountains: it would be necessary to reflect the light from the heliotrope by a second large plane mirror at the central tower of the Observatory, a troublesome procedure which did not appear to be above suspicion.

I had further thought of removing the objective of the refractor, and substituting for it in front of the spectrograph a precisely similar

but some twenty times smaller objective, in order to throw upon the slit a stellar image of one of the larger planets. The brightness of this image would be according to computation sufficient for obtaining a good spectrogram with an exposure of from one to two hours. This procedure, however, also seemed somewhat troublesome, since the large objective had to be removed.

Finally in our repeated discussions of the problem, the idea occurred to Mr. Zurhellen whether it would not be possible to photograph with the spectrograph the starlike, isolated luminous mountain peaks on the night side of the moon near the terminator. We at once made the experiment, which was successful. Unfavorable weather and the circumstance that suitable objects are not always to be found at the terminator, have permitted us to make thus far only the following observations. The exposure and the measurement were made in precisely the same manner as for stars, and the spectrograms do not differ in appearance from those of the stars.

Spectrograms of Isolated Peaks near the Terminator of the Moon

Plate No.	Date G. M. T.	Exposure	Hour Angle	Observed Velocity	Calculated Velocity	$C-O$	No. of Lines	$1/n\ \Sigma v$
		min.		km	km	km		km
1038	1908, Jan. 15.435	65 Z	$+0^h49^m$	+1.12	+0.63	−0.49	18	+1.7
1042	1908, Feb. 10.269	100 Z	−0 19	+2.80	+1.20	−1.60	21	2.1
1043	1908, Feb. 10.351	75 K	+1 37	+3.54	+1.33	−2.21	19	1.7
1045	1908, Feb. 11.378	80 K	+1 28	+1.18	+1.24	+0.06	16	2.1
					Mean:	−1.06		

We shall continue further this series of plates of the lunar mountains until we obtain a fully established value for $C-O$. We may assume from these few determinations *that the radial velocities of the stars communicated above require a small negative correction amounting to about* -1.0 *km.* The correction, when thus determined, will fully eliminate all instrumental and personal errors of the exposure and the measurement, as well as the errors in the assumption of the wavelengths in the comparison light and that of the stars, so that we obtain the correct absolute radial velocities of the stars.

Royal Observatory. Bonn
February 1908

AN EXPERIMENTAL STUDY OF THE LIPPMANN COLOR PHOTOGRAPH

By HERBERT E. IVES

Photography in colors by means of standing light-waves was first accomplished by E. Becquerel about 1850, although he was unaware of the part they played in his results. Zenker[1] developed the theory that the polished silver surface, on which Becquerel's sensitive film was formed, reflecting the incident light, caused standing waves. In the loops of these waves the silver salt was reduced, forming parallel reflecting surfaces distant from each other one-half the wave-length of the incident light. Viewed by reflection, the developed film exhibited color as do thin films of oil on water, or, more exactly, the multiple interior surfaces of potassium chlorate crystals.[2]

Lippmann[3] in 1891 was the first to make practical application of this theory by developing the process of color-photography bearing his name. For the polished silver surface of Becquerel he substituted mercury, which could be flowed behind a transparent fine-grain sensitive film on glass during the exposure, and removed to permit development and the subsequent viewing.

The theory and practice of the process will be found discussed by Lippmann,[4] Wiener,[5] Neuhauss,[6] Valenta,[7] Lehmann,[8] and others.[9] Full use has been made in the following study of the results of their work, and details of theory and experimental methods not new with the writer will not be described at any length.

Good results have been obtained by the process as worked by these

[1] *Lehrbuch der Photochromie*, 1868.

[2] *Rayleigh, Phil. Mag.* (5), **26**, 256, 1888.

[3] *Comptes rendus*, **112**, 274, 1891.

[4] *Journal de Physique*, **3**, 97, 1894.

[5] *Annalen der Physik*, **69**, 488, 1899.

[6] *Die Farbenphotographie nach Lippmann's Verfahren*, 1898.

[7] *Die Photographie in natürlichen Farben*, 1894.

[8] *Beiträge zur Theorie und Praxis der directen Farbenphotographie*, **1**, 1906.

[9] A historical account of the development of the process will be found in *Die Grundlagen der Farbenphotographie*, by B. Donath, 1906.

and other experimenters, but its difficulties have been found so great as to prevent its wide use. Some discrepancies with the theory have been found, and compromises with the best conditions as indicated by theory have been found necessary in practice.

The object of the present investigation has been to see how closely the conditions called for by theory could be approached, to find the cause of some of the difficulties met with in practice, and, if possible, to obviate these.

The separate problems will be stated as they are taken up, but may be briefly outlined here.

According to the theory as stated by Lippmann the most accurate reproduction of color should come from the use of a thick sensitive film, the film gaining in resolving power with the number of reflecting laminae. In practice very thin films have been used; reproductions of the spectrum show, on examination with the spectroscope, that the colors are very far from pure. The first investigation which follows was to determine whether films could not be prepared which would reproduce colors with a fidelity much greater than has hitherto been possible and whose thickness could be increased with corresponding increase in resolving power. The investigation has resulted in a method for producing films having these characteristics.

The production of pictures of natural objects has been a matter of uncertainty and difficulty; the production of whites has been a stumbling-block to many. The manipulation of the plates with the necessity for a mercury-holding plate-holder has been inconvenient. The causes of this uncertainty in results have been studied; the conditions governing the production of white fixed; and a substitute found for the hitherto indispensable mercury mirror.

In addition, an application of the process to three-color photography has been developed.

MANIPULATION OF PLATES IN GENERAL

The transparent fine-grain silver bromide plates were made, with only such changes as are noted, according to the published formulae of Lippmann, Neuhaus, and Valenta. Ordinary "chemically pure" silver nitrate and potassium bromide were used; the gelatine was either Eimer & Amend's "Gold Label," Nelson's "No. I," or a de-

partment store gelatine recommended as the best for puddings, etc., which was found very hard and free from grease. The emulsion was flowed on pieces of crystal plate glass cut three by three inches. A plate-holder not greatly different from that used by previous workers permitted the introduction of mercury behind the plate and in contact with the gelatine.

The scheme of exposure followed throughout was to expose a comparatively large surface (two by two inches) to the kind of light being investigated. This allowed of easy spectroscopic examination besides leaving room for stripping portions to be sectioned.

Development was mostly with pyrogallic acid and ammonia according to the formula of Valenta, with the one change that the pyrogallic acid was used in powder form, added by means of a spoon of proper capacity to the rest of the developer just before use with each plate. The resulting developer was always fresh and of uniform strength. The hydroquinone used in part of the work was made up according to Jewell's formula[1] with the omission of the potassium ferrocyanide.

After development and drying, the pictures were made ready for viewing by cementing a thin prism of small angle on the film to destroy the disturbing surface reflections, and the back of the glass was flowed with asphaltum varnish. The prism is usually cemented on by means of Canada balsam. As, however, the refractive index of the gelatine containing reduced silver is somewhat higher than that of the balsam, some medium of higher index is to be preferred. Gum styrax ($\mu = 1.58$) was found suitable, but the lower surface of the prism must be ground to avoid the reflection at glass-balsam surface. The latter procedure was uniformly adopted. The amount of light reflected from the laminae is at best small, so to obtain the purest colors all addition of white light is to be avoided. This white light may come from the prism-balsam, balsam-gelatine, gelatine-glass, or rear glass surfaces, and if all these reflections are not diminished as much as possible the dilution of colors is quite appreciable. The prism-balsam reflection is overcome by grinding the back of the prism with emery; the balsam-gelatine by correct choice of balsam; the gelatine-glass is unavoidable; the reflection from the back of the glass

[1] *Astrophysical Journal*, 11, 242, 1900.

can be destroyed completely by first grinding with emery and then flowing on asphaltum varnish, preferably mixed with machine oil to prevent its becoming brittle and flaking off. If the pictures are to be observed from the glass side, a second prism is cemented on in place of the black varnish.

When so mounted the pictures are ready for observation. It is of extreme importance that they be observed by parallel light and shielded from all side light. The best conditions are given by a small opening in a wall facing a brilliant white sky. If the observer stands with his back to the opening and holds the picture at arm's length reflecting the sky it appears at its best.

These precautions are most necessary in the case of pictures of natural objects, for reasons which will appear later. Spectra and similar subjects, where the reflecting laminae are numerous and deep in the film, are visible much more easily, but are of course best seen under the conditions given above.

WORK WITH MONOCHROMATIC LIGHT SOURCES

The first investigation was on the influence of two factors, fineness of grain, and film thickness, upon the correctness of color rendering. It is naturally to be expected that both factors will influence this. The smaller the silver particles the more minute the variations in the standing wave-system they will record. The thicker the film the more laminae and hence the greater purity of the reflected light.

There are comparatively few recorded experiments on variations in the size of the grain; the first published emulsion formulae have been closely followed by all experimenters. Cajal[1] recently observed that the size of the grain is influenced largely by the amount of agitation of the emulsion during preparation, and finds that the finer the grain the better the quality of the colors. He, however, was not working with pure spectrum colors. The present investigation of this point was prompted by the observation that when photographing monochromatic light sources for a special application of the process, the use of much less silver bromide gave more satisfactory results. This made it appear of interest to determine from this standpoint the best proportion of silver salt.

[1] *Zeitschrift für wissenschaftliche Photographie*, 5, 213–245, July 1907.

With regard to the best thickness of film, theory would call for the greatest thickness practicable to work. Yet the practice has been to work with extremely thin ones such as can be obtained by flowing the liquid gelatine on and off a warm glass plate. The section photographed by Neuhaus showed but seven or eight laminae. Wiener, by counting the laminae cutting the gelatine-glass surface in a spectrum photograph, found the number less than twenty, obviously too few to have much resolving power, and explaining the impure reflected light. There has indeed been reason to suppose that appreciably greater thickness would not help matters. The loss of light by absorption and reflection at each lamina is large, so that the effect of each lamina becomes rapidly less with increasing distance from the surface of the film, assuming them all equally well formed. Film sections indicate that the latter is not the case; the laminae are of rapidly decreasing strength. Lehmann has calculated, taking into account the effect of absorption, that the laminae should be more distinct, the greater the distance from the mirror. That they are not he ascribes to the reflected light losing the power of interfering after a short distance. These points were considered worth investigating more closely.

The size of the silver grain was varied entirely by the quantity of silver bromide in the emulsion. A set of emulsions was made up in which the content of silver nitrate varied between 0.03 and 0.18 gram per gram of gelatine, the quantity of potassium bromide constantly five-sixths of this. The resulting emulsion had from one-sixth to the same amount of silver bromide as used by Valenta and others. The emulsion was flowed on the level plates in measured quantities from a graduate, so that the thickness was under control. After flowing, the emulsion was pushed to the corners of the plate by means of a glass rod. The quantity used varied from one to ten cubic centimeters on a 3×3 inch plate. This gave films from about 0.007 to 0.07 mm, as sections afterward showed by the number of contained laminae.

Monochromatic green light was used for the greater part of the work. This was obtained from a Cooper Hewitt mercury vacuum lamp, an aperture of 1 sq cm illuminating the plate 25 cm distant. A cell of neodymium ammonium nitrate and potassium bichromate

absorbed the yellow and blue radiations. The plates were made sensitive to this color by erythrosine.

INFLUENCE OF SIZE OF GRAIN

A noticeable increase of purity in reflected light was found as the quantity of silver bromide was reduced. This increase is quite marked between 0.18 and 0.09 grams of silver nitrate per gram of gelatine, after that less so.

Besides the influence on the purity of the reproduced color the quantity of silver bromide affects the sensitiveness of the plates. A rather unlooked for result was that a smaller quantity of silver salt made the plates more sensitive, up to a certain point. This is readily explained; the light must pass through the film, and decreasing the silver content increases the transparency. If the amount of silver becomes too small the plates again become less sensitive. The fastest emulsion was found to be one containing half the silver salt used by previous workers. As this gave practically all the increase of purity resulting from decreased grain it was adopted as the standard emulsion for future work.

The formula and method of preparation were as follows:

A. Gelatine 1 gram	B. Gelatine 2 grams	C. $AgNO$ 0.3 gram
Water 25 cc	KBr 0.25 gram	Water 5 cc
	Water 50 cc	

A and B are heated till the gelatine melts, allowed to cool to 40 degrees, C added to A and then A to B slowly with stirring, the sensitizer added, and the whole filtered. After flowing and setting, the plates are washed for fifteen minutes and allowed to dry.

INFLUENCE OF THICKNESS OF FILM

The first work done on the influence of film thickness indicated that, viewed from the film side, there was no increase of purity with increase of thickness beyond one of about thirty half-wave-lengths, or about that given by flowing the emulsion on and off the cold glass plates. The single green line of mercury was rendered as an ill-defined green band in the spectrum, properly a continuous spectrum with strong maximum in the green. Fig. A, II, gives the mercury green line as rendered by the emulsion found best as above. The green light is considerably more monochromatic than that usually seen

in Lippmann spectra. From the glass side the band was of a different character, showing more clearly defined edges, as given in Fig. A, III. This is explained by the stronger laminae being farther from the eye and by absorption being no more effective than the weaker ones. The reflecting surfaces are then comparable to the lines of a grating, each sending equal contributions to the total reflected light. Owing to the strongest laminae suffering so much absorption, the light from the glass side is much weaker than from the film side.

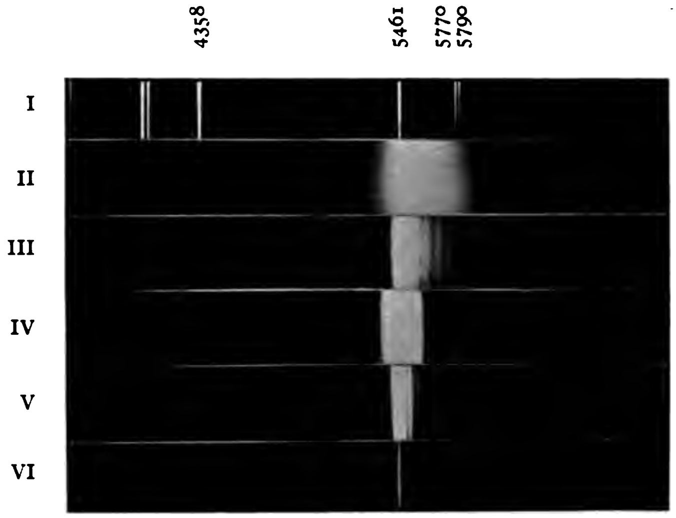


FIG. A

I. Mercury vacuum arc.
II. λ 5461 as reproduced by fine-grain film, with pyrogallic acid development.
III. Same from glass side.
IV, V, VI. Hydroquinone-developed bleached films, 50, 150, 250 laminae.

Even from the glass side, however, increase of thickness beyond the above-given limit produced no corresponding increase of purity. Further light on this question was furnished by studying the effect of varying exposure and development.

EFFECT OF VARYING EXPOSURE

To study this, exposures were made through a graduated wedge of erythrosine solution, opaque to green light. Before noting the effect of varying exposure on the reflected colored light, the appearance of the film at angles other than the angle of specular reflection is worth

describing. By reflected light the film appears in the less exposed parts like an ordinary fine-grain negative, that is, there is a certain amount of diffuse reflection so that a positive image is seen. As the exposure proceeds the diffuse reflection becomes less and less until the film is quite grainless and black, except at the angle of specular reflection, behaving as a piece of unsilvered glass. By transmission the plate is greenish in the very slightly exposed parts, muddy brownish yellowish in the moderately exposed parts; where the film has been exposed until the diffuse light disappears by reflection it is clear, transparent yellow, like a piece of yellow glass. The appearance and behavior of the silver deposit is in all respects as though the particles of silver were first separate, scattering light, and on longer exposure fused together into a homogeneous mass. The appearances here described may be observed on almost any Lippmann photograph viewed at other than the angle to show color, the diffuse deposit forming a positive image which in the fully exposed high-lights appears reversed.

The colored light reflected from the laminae increases in intensity with increase of exposure until the diffusely reflected light disappears; after that for a long range of exposure no change in intensity occurs. This is probably because the individual laminae do not gain in reflecting power after the silver particles have fused together into a reflected surface. This fact makes it possible in photographing spectra with plates not evenly sensitized to secure uniform action throughout the spectrum merely by long exposure.

The greatest spectral purity of the reflected light occurs just before the "saturation" point is reached, dropping slightly for longer exposures and not changing perceptibly till many times the full exposure, when the color tends toward gray and white. From the glass side the purity increases with exposure to a maximum, and then remains constant except with very thin films, in which case the purity again decreases. The cause of this will appear shortly.

EFFECT OF VARYING LENGTH OF DEVELOPMENT

By lowering a plate slowly into the developer different amounts of development were obtained. The only effect of greatly increased development was to cause fog, decreasing somewhat the purity, if the picture was viewed from the film side. Viewed from the glass side

longer development had no effect whatever, except with thin films, when the purity decreased similarly to the effect noted with increasing exposure.

The practice was to develop the plates up to the point where fog began to appear, usually by time development. At temperatures near 20° C. from 45 seconds to a minute gave full development.

ACTION OF THE DEVELOPER ON THE FILM

Using thick films it was found, if development was sufficiently prolonged, that the laminae intersected the gelatine-glass surface, giving a watered-silk effect, the same phenomenon used by Wiener to estimate the thickness of the film. As in film sections heretofore made comparatively few laminae had been found, it has been assumed that but few are formed. The appearance just noted indicated that the laminae might be formed throughout the thickness of the film, provided development were continued long enough.

To study the action of the developer it was decided to section the films and observe them under the microscope. This has been done by Neuhaus, Lehmann, and Cajal. The latter swells the section in water to bring the structure, in its natural size too small to be satisfactorily resolved with the microscope, within reach of average powers. This method was pursued in the present investigation. After development a small oblong of film was cut out with a knife and then stripped from the glass by means of a narrow, straight-edged chisel. The strip of film was then laid on one-half of a split piece of pith. When dry the other half of the pith was laid over it, the whole placed in a microtome and sectioned. On laying the sections on a microscope slip, and wetting with a drop of water, the majority of the laminary structures were easily observable with a one-sixth inch objective. For much of the work where it was not important to have sections of exactly the same thickness, it was found convenient to dispense with the microtome, simply hold the pith in a pair of clothes pins and shave off sections with a razor guided by the forefinger, an operation easily performed after a little practice.

A section of a normally exposed and developed film is shown in Fig. 5 (Plate XIX). It will be observed that the laminae are strongest at the mirror-surface, decreasing in strength with distance from it.

Figs. 6 and 7 (sections of same thickness) show the results of short and long development. With short development the laminae are visible for only a short distance; with long development the laminae are present to a great depth, but a thick band of fog has progressed inward from the surface. The laminae corresponding to the surface ones in the short development are therefore in the long development at a greater depth. From the glass side their effect is precisely similar, unless the film is thin or development has been very long, in which case the fog band reaches to the glass and drowns out the clearly formed laminae. This makes clear the above-noted effects of long exposure and long development as seen from the glass side. A film exposed or developed progressively from edge to edge possesses a layer of well-formed clean laminae running diagonally down from the surface until the glass is reached.

It appears, therefore, that the standing waves are actually formed to a greater depth than has been supposed. To verify this several experiments were performed. A thick film was exposed as usual, then before development wetted and a piece stripped from the glass and so developed from both sides. A section showed the laminae to be formed equally well at both developed surfaces. This is shown in Fig. 8, where 150 distinct laminae may be counted. Another experiment consisted in flowing a plate with a thick solution of celluloid varnish, through which, after drying, the exposure was made as usual. On stripping the varnish coating from the gelatine, developing, and sectioning, laminae were found all through the film. They are, therefore, formed, with monochromatic light, under the conditions of this work, to a much greater depth than the thickest film used.

It follows from these observations that the small effective number of laminae (about 20 or 30 at the most) is due, not to few being formed, as has been assumed, but to the mode of action of the developer. This invited investigation of different modes of development and different developers, from which has resulted a substantial advance in the rendering of pure colors.

Experiments with different modes of development, using the same developer (pyrogallic acid), led to no results. Development with strong developer, with weak slow developer, and with a large proportion of bromide, showed no material difference in the character of

the deposit. Long development followed by application of weak Farmer's reducer was unsuccessful, as the reducing solution simply destroyed everything as it slowly worked through the film.

Attention was then turned to other developers with immediately gratifying results. Ferrous oxalate, glycin, and hydroquinone were tried. All of these developed with great uniformity throughout the depth of the film, without causing fog. Fig. 9 shows a section of film developed with hydroquinone, and should be compared with Fig. 6. Unfortunately, as it seemed at first, the deposit with these developers is black and opaque, making the reflected color dull in the extreme, and the absorption so great that only few of the laminae are effective. To obviate this difficulty the expedient was adopted of bleaching the film with mercuric chloride. This has been done previously by Neuhaus and results in a white, very transparent film. The reflecting power of the bleached deposit is not great, so that luminosity is lost with pyro-developed plates. With plates developed by the three above-mentioned developers this loss of reflecting power is more than compensated for by the greater number of effective laminae. So transparent is the deposit that the absorption is negligible and all the laminae act with practically equal strength. Consequently, instead of the reflected light being a somewhat diffuse band in the spectroscope, it is a narrow bright line. Moreover, increased thickness with consequent greater number of laminae gives increased purity. Practically it was found possible to run the films up to about $\frac{1}{10}$ mm (as determined by the number of laminae in sections) with continued increase of purity. A line source is reproduced by such a film as a brilliant line of about 20 Å. U. width. By transmission a narrow absorption line appears in the spectrum indistinguishable in a small spectroscope from a Fraunhofer line. In Fig. A, IV, V, VI, are shown spectra of the mercury green line as reproduced by films containing approximately 50, 150, and 250 laminae. It will be observed that films of this character might serve for sources of comparatively monochromatic light.

The thickness to which the film may be carried is limited by the thickness of gelatine it is practicable to flow and dry satisfactorily. Greatly increased exposures due to the opacity and slow speed of the thick films made work with them difficult, but the conclusion may be

drawn from this work that the purity of reflected color is, with this procedure, directly dependent on film thickness. It is only a matter of emulsion making and flowing technique to secure films of as high esolving power as one desires.

MIXED COLORS

GENERAL THEORY

Mixed colors, such as two or more spectral lines, or the broad ill-defined bands of the spectrum given by pigment colors, give standing waves which may be compared to the interference fringes they would give in a Michelson interferometer. That is, we have regions in the film where the different wave-lengths acting reinforce regions where they oppose each other. The visibility curves,[1] therefore, are applicable to the structure of the Lippmann film. Fig. 1 gives the resultant

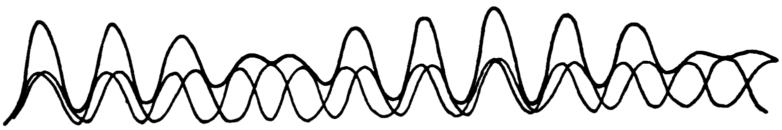


FIG. 1.—Standing Wave System Due to Two Wave-Lengths.

of two wave-lengths, while the visibility curves figured show the manner in which we may expect the laminae to be distributed for various types of incident light. Photographs have been published by Lehmann showing that the resultant structure for two radiations agrees with the calculated. Fig. 12 shows a section of a film exposed to four radiations. The periodic variation in the clearness of the fringes corresponds to the variations of visibility of interferometer fringes.

Two points in connection with the reproduction of mixed colors were studied as of special interest. The first was the question of the degree of complexity of incident light the film is capable of recording. The second was the question of the luminosity values of mixed colors as compared with the component pure ones.

As to the amount of complexity in the incident light which may be reproduced, it is at once apparent that this is dependent on the effective thickness of film. A film developed with pyrogallic acid is, from the previous work, unsuitable where depth is called for, hence the

[1] A. A. Michelson, *Phil. Mag.* (5), **31**, 338, 1891; **34**, 280, 1892.

best results in the way of resolving power were obtained from hydroquinone-developed, bleached films.

Parallel series were carried out on films of the two types. These consisted in exposures to two, three, and four different wave-lengths, and to a broad spectrum band with sharply defined edges.

With pyrogallic-acid developed thick films, the greatest number of separate wave-lengths reproduced was three, and the result was merely a continuous spectrum with three maxima; four radiations produced ill-defined irregularities. The mercury yellow and green lines were well separated with such a film and probably somewhat closer lines would be. A sharp spectrum band of 600 Å. U. width in the green was rendered as a maximum in the green, but all trace of sharp limits was missing, the reproduction being identical with that of the transmission band of a naphthol green-dye solution. This is to be expected, as examination of Fig. 2 shows. The first part of the standing wave-system of the two types of color is identical, and in a thin film, or one whose effective portion is thin, will reproduce as such. The effect of development with pyrogallic acid is in short to reduce all colors to one general type.

With hydroquinone developer and bleaching, two, three, and four radiations were reproduced satisfactorily, except for loss in luminosity, the cause of which will be taken up presently. The spectrum band was reproduced with well-defined edges. From these tests it was concluded, as with monochromatic light, that the capacity of the film to reproduce any form of complex radiation is only limited by the gelatine thickness possible to be obtained practicably.

The second point studied, that of luminosity rendering, will be made clear by some considerations of the theories advanced as to the nature of the reflecting elements in the film. Lippmann developed the theory on the basis of minute reflecting particles distributed through the film. White, for instance, is due to a continuous irregular distribution of such particles. According to this view all the incident light produces reflecting deposit. Schütt[1] advanced the theory that the action of the light is merely to produce a periodic change in the refractive index. Wiener showed that the reflection in the case of bromide of silver plates was from metallic particles. It is possible,

[1] *Annalen der Physik*, **57**, 533, 1896.

for instance, by exposing films of bichromated gelatine, to secure pictures in which the only change produced is in the refractive index.

The luminosities of all but monochromatic pictures will be rendered radically differently according to which mode of reflection takes place. For illustration take white. In the one case we have a large number of reflecting particles, in the other a single reflecting surface, practically the surface of the gelatine. A monochromatic source would give many such surfaces through the film with the structureless deposit and would be far more brilliantly rendered than a white visually as brilliant. Where two or three colors act together there are regions of the film in which, while the total amount of light action is say half the maximum amount, yet sharp changes of intensity are missing. If reflection is due to abrupt change of refractive index these portions would contribute little. A loss of luminosity of the combined with respect to the component colors would result. If this were marked, colors with two or more maxima, such as purple or a subjective yellow, would be weakly reproduced. Lehmann, working with superposed spectra, notes such a loss. The experiments which follow were made with the two kinds of development, and because of the large surfaces exposed, and the manner of exposing, critical examination was easy.

The first experiment was to mix two and three colors (red, yellow, green, and blue, in various combinations) under such conditions that their resultant intensity when acting together could be compared with their intensity separately. The apparatus used consisted of an opaque line screen, opaque spaces twice the width of the transparent, 100 lines to the inch, which was cut in two, and one half turned at right angles to the other. This was placed directly in front of the plate and by means of a screw could be moved any desired distance in the direction of the lines on one half. This motion caused one set of lines to uncover one-third of the surface at a time, the other to continually expose the same strips. In one half would therefore be obtained the three colors superposed, in the other half juxtaposed, in which case the mixing would be visual.

In carrying out this experiment the greatest care had to be taken to avoid the effects of overexposure. As we have seen, exposure beyond a certain point causes no increase of brilliancy. Hence if

each exposure was a full one we would have the entirely covered surface three times as brilliant (with three colors) as the partially covered, indicating a large luminosity loss in the superposed as compared with the juxtaposed. This was avoided by limiting the exposures so that the total exposure with all colors would not reach the saturation point.

The result of the tests was that with pyrogallic acid the loss of luminosity with two colors, as long as exposure was carefully kept below the saturation point, was hardly noticeable, the only effect being a slight tendency of the superposed colors to shift toward shorter wave-lengths. With three radiations a quite perceptible loss of luminosity was observable. In either case exposure beyond the saturation point caused loss of luminosity. With hydroquinone the luminosity loss was much more marked.

The most instructive test was to expose a plate to light of the green-mercury line and to a visual match in color and intensity consisting of a spectrum band of 600 Å. U. width. These gave equal densities in the negative. With hydroquinone development and bleaching the monochromatic side was many times the brilliancy of the other. With pyrogallic acid the two sides were nearly the same luminosity, the complex radiation only slightly less luminous.

Experiments on photographing natural objects whose colors are for the most part continuous spectra with diffuse maxima, besides showing the necessity for a reflecting deposit, emphasized the necessity of this being of high reflecting power. Very fine-grained emulsions proved unsuitable for the reproduction of such colors in their luminosity values, and satisfactory results were obtained only when the silver content of the film was made as large as would still give color. The reason is at once apparent when we observe that the colors under consideration give at most only a few laminae near the surface, as shown in Fig. 2 and in the photographed section, Fig. 13. It is necessary not only that the reflecting power of these be large but that the diffuse deposit behind contribute a share of light in proportion to the light acting to produce it. If the grain is too fine these experiments and work with white light indicate that the separate particles do not act as reflecting surfaces.

The outcome of the experiments is to indicate that with a fairly coarse grain, overexposure being carefully avoided, developed with

pyrogallic acid, there is probably a close approach to the condition of separate reflecting particles. With complex radiation, or with over-exposure, there cannot fail to be a certain amount of fusing together and consequent luminosity loss, and in the underexposed parts there is probably also a loss through the formation of deposit not starting

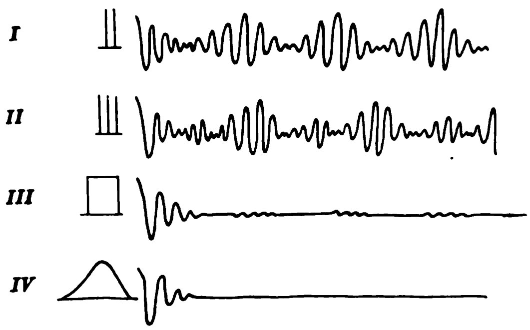


Fig. 2

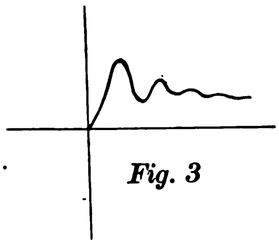


Fig. 3

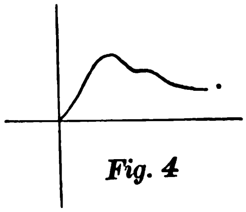


Fig. 4

FIG. 2.—Visibility curves for various sources:

I. Two monochromatic sources.
II. Three monochromatic sources.
III. Spectrum band with sharp limits.
IV. Type of spectrum of light from most natural objects.

FIG. 3.—Standing waves formed by white light from red to blue, as recorded in fine-grain emulsions.

FIG. 4.—Standing waves formed by white light from infra-red to ultra-violet, as recorded by coarse-grained emulsions.

till the light attains a certain intensity. With hydroquinone development and bleaching, the reflection is evidently more nearly of the type caused by changing refractive index.

This at once makes evident that for all photography where luminosity values must be preserved, a developer like pyrogallic acid giving a highly reflecting yet fairly transparent deposit is essential. On the

other hand, where complexity of spectral structure is to be reproduced, a deep-acting developer, which by proper treatment will give a transparent deposit, is desirable.

THE PRODUCTION OF WHITE

On Lippmann's theory, white is produced by reflection from particles of silver thickly and irregularly distributed through the film. Regularly spaced laminae would be entirely absent. Such a deposit would be formed in a perfectly isochromatic emulsion, provided the wave-lengths of the acting light varied between wide limits and the individual silver grains were of appreciable size. If, on the other hand, the acting light varied between rather narrow limits of wave-length, as from red to blue, the size of the silver grains being negligibly small in comparison to the shortest wave-length, a rapidly damped standing vibration of wave-length equal to the mean incident wave-length would result. In Fig. 3 is given the standing wave form due to light from red to blue, in Fig. 4 the form when the incident light is from infra-red to ultra-violet and the silver grain coarse.

Lippmann pictures have been made, exhibiting beautiful whites, yet general difficulty seems to have been experienced. This is partly due probably to the difficulty, with present known sensitizers, of securing isochromatism between wide limits. Several other theories have been proposed and other experimental methods tried to produce white. Lehmann concludes that the greenish appearance sometimes found in whites on short exposure is due to laminae formed in the manner described above. He corrects this by using a screen with three maxima of transmission: red, green, and blue. On short exposure whites will be reproduced as a mixture of these three colors. A serious objection to this method is that colors falling in the minima of transmission will be poorly reproduced.

Cajal from his work concludes that white is due to the formation of a mirror-like surface on the film and that this can be produced only by the use of amidol as an intensifier. The mirror-like appearance presented by the high-lights of Lippmann pictures readily lends itself to the idea that the surface is a silver mirror. That this is possible only when the picture is intensified with amidol is, however, a conclusion unsupported by other experimenters and contradicted by the

undoubted production of white by Neuhaus and others who did not use this intensifier.

The possible modes of production of white are therefore three: first, by a general diffuse deposit as an isochromatic emulsion; second, by forming laminae corresponding to red, green, and blue; third, by producing a mirror surface. The second method was not tried in the present investigation, as being obviously a compromise.

Attention was therefore turned to producing an isochromatic emulsion by combinations of color-screens and sensitizers. Numerous sensitizers were tried; of these much the best was isocol, in that it imparts a sensitiveness free of gaps or maxima. The sensitiveness given by it extends from deep red to blue and violet, gradually increasing toward the latter. Absorbing solutions of wool black, cobalt sulphocyanate, and iron sulphocyanate reduced the action in blue, green, and yellow to that in deep red and gave very satisfactory isochromatic action from red to ultra-violet.

Plates similar to those used in the study of monochromatic colors were prepared and exposed to white, at first with disappointing results. Not only was there practically no light reflected from the partially exposed parts, but the mirror-like high-lights were absolutely black. By intensification with amidol the plates could be made to reflect considerable light. This led to the question whether the intensifier did not merely increase the size of the grain, and whether this might not be done in the emulsion. That the grain was too fine to give whites by diffuse reflection was also indicated by the fact that a fogged plate appeared black and not white by reflection.

A series of emulsions were then made up containing increasing quantities of silver. These were exposed without the mercury mirror and the character of the deposit examined. It was at once apparent that while a very fine grain reflected diffusely very little light indeed, a coarser grain gave a strong white reflection which in the high lights became mirror-like. The brightest whites were given by an emulsion containing four times the silver content of that used for pure color work, or twice that used by Lippmann and others. This emulsion used with the mercury mirror gave perfect white. The theory that diffusely distributed reflecting particles formed in an isochromatic emulsion produce white is therefore supported.

As to the theory of Cajal that white is given only by a mirror-like surface, this was not supported by the results here obtained. The whites were quite perfect in the partially exposed parts. In fact it is the writer's opinion that the formation of the mirror appearance indicates rather the point where the white ceases to be good. A very slight exposure beyond this point, giving the clear yellow by transmission, results in the white becoming black. Everything is in agreement with the view before advanced that the mirror appearance is due to the merging-together of the separate particles with resulting loss in reflecting power. White will be given only so long as the particles are separate, being similar therefore to the white given by powdered glass or other substance transparent in the fused condition.

Since the range of sensitiveness of the emulsion is at best rather limited, and since the grain must be kept small enough to render all colors ordinarily met with, it would not be surprising if some tendency should exist to form laminae corresponding to the mean wave-length, i. e., green. No appearance of green on underexposure of whites was observed. Before mounting the prism the film had an orange tinge which turned to greenish on increasing the angle of incidence. The explanation of this is given by Fig. 4. Although complete laminae corresponding to green light are not formed the deposit of silver increases in density from the surface to the point where the first lamina would form. Rapid damping prevents the formation of more surfaces. There is therefore a slight gap between the surface and the heavy deposit, forming a single thin film. On mounting the prism the upper surface is virtually destroyed. The orange color is what we should expect from Wiener's explanation of the shift of all colors toward red as long as the surface reflection is active.

Sections supported these conclusions. Laminae were absent; in their place appeared a structureless deposit, increasing in strength toward the surface, reaching a maximum a short distance from it, the maximum corresponding to the distance in of the first laminae due to green light, as nearly as could be determined. This appearance is shown in Figure 11.

PHOTOGRAPHY OF NATURAL OBJECTS

To photograph natural objects conditions must be such as to give whites and colors of small spectral purity. This is secured by using

a fairly coarse-grained isochromatic emulsion developed with a developer giving a transparent highly reflecting deposit.

For experiments in this direction a number of different emulsions and modes of preparation were tried. Good results were obtained with very coarse-grained ones, but experience showed the proportions of silver bromide and gelatine in general use to be probably the most satisfactory. Little choice exists between the several modes of preparation published. The silver nitrate may be digested with part of the gelatine; dissolved in water and added, before mixing, to one part of the gelatine; dissolved in water and added to the gelatine containing the potassium bromide; or added in dry powdered form to the latter. The quantity of silver bromide is double that found best for monochromatic light-reproduction.

To secure isochromatism, isocol as a sensitizer, with the absorbing solutions above given, or, as the sensitiveness imparted by isocol is very fugitive, a more permanent combination of pinacyanol and pinaverdol, with a screen of wool black, was found to answer fairly well.

The only point in the manipulation not yet described is the choice of film thickness. The standing wave-structure being shallow, great thickness is no object. Speed, too, is gained by small depth. The thinnest film is obtained by flowing the warm emulsion on and off glass plates warmed to the same temperature. This gives a thickness of about $\frac{1}{400}$ mm, on which most colors reproduce satisfactorily as far as the eye can tell. The resolving power is small of course, and some anomalous results are to be expected. Purple is about the only color of any complexity often met with, and the film should be thick enough to resolve its two maxima well. The most satisfactory thickness was obtained by flowing the emulsion on and off glass plates at room temperature, about $\frac{1}{200}$ mm. Exposures with $f/3.6$ on sunlit objects ranged from $1\frac{1}{2}$ to 5 minutes according to sensitizers, etc.

With emulsions made up and used in this way good color rendering was obtained. The sum total of the results on photographing natural objects has been to vindicate the procedure indicated by theory and carried out by Lippmann. The deviations from that procedure by Lehmann and Cajal seem unnecessary to secure successful results.

The difficulties noted by all workers with the process as applied

PLATE XIX

5 6 7

13 11

8 9 10 12

5. Section of film exposed to λ 5461, developed with pyrogallic acid.
6. Film developed one minute with pyrogallic acid.
7. Film developed 15 minutes with pyrogallic acid.
8. Film stripped and developed from both sides.
9. Film developed with hydroquinone.
10. Bathed plate.
11. White (short exposure).
12. Four wave-lengths: λ 6439, 5780, 5461, 5086.
13. Heterogeneous green light; napthol-green color-screen.

to photographing natural objects were found to be very real. They are in brief the great dependence of success on correct exposure and development. Very slight deviations will make the colors either weak or diluted with white. This is due to the laminae being few and close to the surface. With pure colors a certain amount of clogging up affects but a small part of all the laminae, in diluted colors practically all. A larger proportion (twice as much) of bromide in the developer than was used for pure colors was found materially to help the brilliancy of these colors. A larger percentage of failures is to be expected in any process of color photography than with black and white, since the eye is more sensitive to errors of treatment where color occurs. The sensitiveness of the Lippmann process to slight deviations from correct conditions is, however, much greater than the three-color method, and good results come only from repeated patient trials. When obtained they are extremely dependent on correct viewing conditions, to appear to any advantage. The colors being formed for the most part by two or three laminae backed up by a diffuse deposit, great care must be taken to exclude all light except that coming in the direction to be regularly reflected by the laminae. Light from other directions is not sent to the eye by the laminae but is by the diffuse deposit, causing a drowning-out of the colors with white light. By making the film excessively thin so that the laminae are formed, but not the deposit behind, the colors are more brilliant and less affected by conditions of illumination. Colors of any complexity, such as purple, however, suffer.

A SUBSTITUTE FOR THE MERCURY MIRROR

One of the obstacles to wide use of the Lippmann process is the necessity for a mercury mirrror. Each plate-holder must be arranged as a tank into which before exposure mercury must be flowed. Several attempts have been made to obtain substitutes for the mercury. Krone[1] dispensed with it altogether, relying on the gelatine-air reflection, but the colors are then dull and unsatisfactory. Lehmann has flowed the emulsion on a collodion-coated polished metal plate. After exposure the composite film could be stripped and placed on a glass plate. Pure colors, spectra, etc., can be so reproduced, but those

[1] *Darstellung der natürlichen Farben durch Photographie*, 1894.

whose lamina system is close to the surface cannot, since that space is occupied by the collodion. Placing a silver mirror in close contact with the gelatine has the same objection.

The writer has recently discovered a substitute for the mercury mirror, of a form which permits the plates to be handled and used precisely as ordinary dry plates.

The procedure is as follows: A glass plate is heavily silvered and then flowed with a thick solution of celluloid in amyl-acetate. When this varnish is dry the plate is placed under water; this slowly works under the coating of celluloid, lifting it from the glass, and *bringing with it the silver.* This flexible silver mirror is immediately laid, silver surface down, on a wet Lippmann plate and allowed to dry there, a necessarily somewhat slow process. When dry, the gelatine film has the silver surface in optical contact with it. The plate may be then exposed at any time in an ordinary plate-holder. After exposure the celluloid film is stripped from the gelatine, taking with it most of the silver, the plate developed, and after thorough washing, the remains of the silver are removed with a tuft of wet cotton.

This substitute works perfectly for all types of colors, and except in the laboratory where a convenient dark room makes the use of the mercury mirror simple, facilitates the practical working of the process. Especially would it do so for the photographer who buys his plates ready made. In that case the only difference between ordinary and color photography would be the longer exposure in the latter case, and the necessary mounting of a prism on the picture, and of course the impossibility of copying.

A difficulty which has proved rather troublesome is that some of the best sensitizers are apt to lose their effect during the slow drying. Erythrosine acts perfectly; pinacyanol and pinaverdol are apt to fail. This can probably be overcome, either by different choice of sensitizers, by so treating these that slow drying does not harm, or perhaps by finding some more porous substance than celluloid which, acting the same in other respects, will permit quick drying. Collodion has been tried, but has not been found to strip off the gelatine well.

THREE-COLOR INTERFERENCE PICTURES

The capacity of the Lippmann film to reproduce pure spectrum colors easily and with certainty adapts it for an application to the

three-color process, published by the writer some time ago.[1] In the synthesis of the properly taken records of the three-color sensations spectrally pure red, green, and blue light are called for. The Lippmann film furnishes an unequaled means for securing these.

The method used was to place before the plate an opaque-line screen, having opaque spaces twice the width of the transparent. The three positive color records were projected one after the other with their appropriate colored lights, the line screen being moved each time the width of a clear space. The result was similar to the Joly picture, consisting of alternating lines of red, green, and blue.

In the first pictures so made the colored lights were obtained from sunlight by a monochromatic illuminator, but satisfactory purity and shortness of exposure were not secured. In experiments since carried out the line screen was removed from contact with the plate, as this necessitated a narrow source of light, and placed in contact with the three-color positive, an image of the screen and positive being formed by a Planar lens of fine defining power. For light-sources the cadmium red line (λ 6439), the magnesium green (λ5170), and the lithium blue (λ 4602) were found most available, obtained in the manner described in a following section.

The three-color interference pictures so made are of great brilliancy and beauty, especially if the hydroquinone development and bleaching are used, when the component colors are of practically ideal purity. Quite long exposures are necessary, amounting under the best conditions to a total of fifteen or twenty minutes. This time can probably be materially reduced. The pictures are, however, far more easy and certain besides being more brilliant than the regular Lippmann picture. They constitute an excellent means of carrying out the three-color principle, and have the interesting property of owing their color to the direct action of light and not to pigments or colored glasses as do the other three-color schemes. They can, besides, be duplicated indefinitely.

SENSITIZERS

During the progress of the work various color sensitizers were used, depending on the portion of the spectrum photographed. The list included erythrosine, cyanin, pinacyanol, pinaverdol, pinachrome,

[1] *Physical Review*, **24**, 103, 1907.

isocol, homocol, and dicyanin. For bathing $\frac{1}{100000}$ solutions in water were used, without ammonia; in the emulsion about one cc of a $\frac{1}{1000}$ alcoholic solution to 100 cc of emulsion. Some observations of their behavior with these very slow emulsions are of interest.

In general it was found that bathed plates acted more cleanly and brilliantly, two sensitizers, isocol and homocol, acting very poorly in the emulsion. Ammonia was not used as it has a tendency to make the plates ripen, with consequent great increase in the grain. Bathed plates were, however, unsuitable for a large part of the work, since the sensitizing action extends only a short distance into the film, even with long bathing. Fig. 10 shows a section of a plate bathed fifteen minutes in a $\frac{1}{100000}$ solution of homocol.

For green all of the sensitizers are good except cyanin, dicyanin, and pinacyanol. For the red, pinacyanol is far and away the best, the action of cyanin not extending far enough down, and that of dicyanin being too feeble. The great difficulty has been to sensitize for the light blue. On ordinary plates there is apt with many sensitizers to be a minimum in the blue green near λ 5000. On these slow plates this gap is in the blue. This is owing to the natural sensitiveness of the plates only extending to the violet, while with fast plates it goes down to the blue. The descending curve of green sensitiveness imparted say by erythrosine meets the descending curve of the emulsions' own sensitiveness in the one case in the blue, in the other in the blue green. This was verified by greatly reducing the amount of sensitizer when the weak blue sensitiveness was stronger than the imparted sensitiveness in the blue green. This behavior of the plates makes sensitizer combinations, such as pinacyanol, homocol, and pinaverdol,[1] which fill the blue green in ordinary plates, inefficient here. A blue sensitizer, not needed for fast plates, is really required with the Lippmann plates. Isocol was the only sensitizer found which gave a sensitiveness free from gaps.[2]

As to the keeping qualities of the sensitized plates, it was found that the erythrosine-cyanin, or erythrosine-pinacyanol emulsion plates kept

[1] R. J. Wallace, *Astrophysical Journal*, **26**, 299, 1907.

[2] The sensitizers used were of the following makes or sources: pinacyanol, pinaverdol, pinachrome, dicyanin, from Meister, Lucius, and Brüning; isocol, homocol, from the Bayer Co.; cyanin from Eimer & Amend, New York; erythrosine, from F. A. Reichardt, New York.

well, at least for a week or two. Bathed plates lost their sensitiveness quite rapidly; isocol-bathed plates in four or five hours, rendering them useful only for quickly carried out experiments. Pinaverdol in the emulsion in one case lost its action in four days. Pinacyanol and pinaverdol emulsions which dried slowly, as those prepared for use with the silver-celluloid mirror, sometimes showed complete loss of color-sensitiveness.

SOURCES OF MONOCHROMATIC LIGHT

In the study of monochromatic light reproduction and in making three-color interference pictures difficulty was experienced in finding suitable monochromatic sources. As the plates are very slow, and large surfaces were illuminated, sources capable of giving a large quantity of light for a long period were essential. Many ordinarily used sources were useless, either because of their small intrinsic brilliancy, or because of their too short life. The spark, the vacuum tube, the flame, arcs between easily melted metals, were among these. Another requisite was that the line used should not be so near other lines as to render its separation impossible by means of absorbing screens; resolution by means of a prism causing too much loss of light.

The following list of the most satisfactory sources found is given as of possible use in other lines of work where great intensity for a long period is required. It is by no means complete, since search was stopped when a satisfactory one for any color was found. Where obtainable the best sources are undoubtedly the Heraeus fused quartz lamps and the mercury vacuum arc. The open arcs here tested are as a rule more brilliant and are easily manipulated. Carbon was used uniformly as negative electrode:

Red. Lithium λ 6708. Lithium sulphate in cored carbon.

Cadmium λ 6439. Cadmium ordinarily burns with dense brown fumes which form a cake of brown oxide around the rapidly melting electrode. This may be avoided by melting the cadmium into a copper tube. The copper and cadmium lines appear together, but the red cadmium line is distant from the copper lines. A current of not more than four amperes is best.

Orange. Lithium λ 6103. Lithium sulphate in cored carbon.

Yellow. Sodium λ 5893. Sodium chloride in cored carbon.

Green. Thallium λ 5360. Metallic thallium in cored carbon.

Magnesium λ 5162. Magnesium powder in cored carbon.
5172
5167

Silver λ 5460 and 5209. Silver, which in rods melts in a few secon burns steadily and brilliantly if a thick wire is placed in a co carbon. Wire of 2 mm diameter in a carbon of 10 mm diame gave excellent results.

Cadmium λ 5085, obtained from an alloy of tin and cadmium ir cored carbon, one part by weight of cadmium to six of tin.

Blue. Lithium λ 4602. Lithium sulphate in cored carbon.

Solutions of various aniline dyes separated most of these clear Copper chloride was found useful when either end of the spectru was to be absorbed. With increasing concentration its absorpti moves in, maintaining constantly a sharp boundary. Care must l taken that the temperature of the solution does not rise while in use this causes widening of the absorption.

MISCELLANEOUS PHENOMENA

Relative position of reproduced with reference to incident wav lengths.—Owing to the partial solubility of the gelatine and perhaps th washing-out of unaffected silver bromide the films show a gener tendency to shrink in development and washing. This causes th colors to shift toward blue. This tendency is much more marke when the plates are fixed with "hypo." In most of the work fixin was dispensed with, Lehmann having found the pictures to kee perfectly without. This shift is much more marked with pure color than with mixed, the interlaminary spaces being freer of deposit. Thi is well shown by photographing a continuous spectrum, using a rathe wide slit, beside a line spectrum; the lines are reproduced as notice ably of shorter wave-length tint. If the slit is then closed up to ex treme narrowness and exposure is made, the spectrum colors agree i tint with the monochromatic lines.

Bleaching with mercuric chloride, on the other hand, swells th film; the two processes of fixing and bleaching therefore tend t neutralize each other.

In working with very thick films a spurious "Doppler effect

frequently occurs. The surface portions of the film wash away more than the deeper, so that a diffuse band of light appears on the blue side of the sharp line.

Characteristic curve.—In the photographic plate the density by transmission varies nearly directly with the time of exposure. This is because the deposit of silver is in logarithmic relation to the time of exposure, and the increase of opacity of an absorbing medium also follows such a law. When the deposit is viewed by reflection this relationship between exposure and intensity does not hold, the relation becomes logarithmic instead of linear. The exact relationship is complicated by absorption, which tends to hasten the "saturation point." A further complication arises in the Lippmann process with very short exposures, owing to the necessity for the reflecting particles to have a certain size and a certain closeness to each other to form a regularly reflecting surface. This was observed in a plate one-half of which was exposed behind a coarse opaque grating with lines covering $\frac{2}{3}$ of the surface. The part behind the grating was exposed to nearly full exposure, the part not covered exposed until, when held at arm's length (where the lines were no longer visible), the two parts appeared of exactly the same density. By reflection the portion only partly covered by the full exposure was much more brilliant than the portion completely covered by the shorter exposure.

These several effects tend to shorten the scale of gradation of the plate, unfortunately, because the eye is more sensitive to this defect in colored than monochromatic pictures.

Different rates of development for different colors.—In developing three-color negatives where all three images are on one plate it has been observed that the three images develop at different rates although the exposures and the final densities are correctly proportioned. The Lippmann film exhibits the effect clearly. In making three-color interference pictures the colors were found to depend considerably on the time of development. With short development the green and blue predominated, with longer the red became stronger, the final picture showing, however, the relative exposures not too long for blue and green. Trouble from this effect was easily avoided by keeping the time of development constant and regulating the exposures for that development.

SUMMARY OF RESULTS AND CONCLUSIONS

Reproduction of monochromatic light.—A smaller amount of sil bromide than usually employed gives purer reflected light from t Lippmann film.

Increase in thickness beyond about $\frac{1}{200}$ mm causes no correspon ing increase of purity so long as pyrogallic acid development is us

The standing waves are formed throughout the thickness of t film; non-formation of laminae is due to surface action of the develop

Other developers such as hydroquinone develop evenly through t film. By bleaching the deposit formed by their use films are obtain giving purer reflected colors than heretofore obtained and increasi in resolving power with thickness.

Mixed colors.—Films developed with pyrogallic acid have sm capacity for rendering complex structure, but luminosity values a well preserved if the grain is not too fine or exposure too long.

With hydroquinone and bleaching, complex radiations are pr duced with a fidelity dependent only on the practically attainab thickness of film. This resolving power is at the cost of luminosi

White.—White is produced by the action of white light on fai coarse-grained rigidly isochromatic emulsions.

Natural objects.—The colors of natural objects are well reproduc by emulsions suitable for giving whites and mixed colors, i. e., somewhat coarser grain than is best for pure colors.

Pictures of natural objects are more difficult to obtain than tho of pure colors because of shallowness of the standing wave-structur

Substitute for the mercury mirror.—A means has been found of affi ing a silver reflecting surface in optical contact with the film, enablin the mercury mirror to be dispensed with.

Three-color interference pictures.—The Lippmann film, by reaso of its capacity for reproducing pure colors, is well adapted to appl cation to three-color photography.

In conclusion I wish to acknowledge my indebtedness to my fathe Mr. Frederic E. Ives, whose life-long experience with photograph processes has always been freely placed at my service. I also wish t thank Professor J. S. Ames for the kindly interest he has shown i the progress of the work.

JOHNS HOPKINS UNIVERSITY
March 1908

THE PRODUCTION OF SPECTRA BY AN ELECTRICAL RESISTANCE FURNACE IN HYDROGEN ATMOSPHERE

By ARTHUR S. KING

The purpose of this paper is to give the results of a series of experiments in which spectra were obtained by means of a tube-resistance furnace in an atmosphere of hydrogen. Briefly stated, the method was to pass a heavy alternating current through a graphite tube placed in an air-tight chamber filled with pure hydrogen, thus heating the tube to incandescence and vaporizing the metal or salt placed therein. The distinctive points of the method are twofold: (1) the elimination of the electrical action given when the incandescent vapor carries the electric current, as in the arc and spark; (2) the avoidance of the chemical action of unknown character and magnitude which takes place in the flame. We have thus to deal with a spectrum given at a temperature which may be regulated by the strength of the heating current, with no supply of oxygen present, and when the possible chemical action is very limited.

The investigation was directed along two lines: (1) to see whether the spectra of certain elements could be obtained under conditions approaching so nearly to a "temperature spectrum" as we have here and what conditions modified the spectrum; (2) to make a more intensive study of certain spectra for which a considerable number of lines were obtained, comparing the lines and their relative intensities with those given by other light-sources.

Apparatus.—The chamber to contain the resistance tube was a brass cylinder of 10 cm internal diameter and 40 cm length, with an extension tube at one end closed by a window, while the other end of the cylinder was closed by a cap clamped on and fitting tightly with a rubber washer. This cap could easily be removed and had a short extension tube coaxial with the main cylinder, closed by a window. The graphite resistance tube was supported in the middle of the cylinder, its axis being in a line with the window tubes, so that the interior of the incandescent graphite tube could be observed

from either end. The support of one end of the furnace tube made contact directly with the side of the brass chamber, while the support of the other end was insulated and connected with a heavy copper terminal passing out through an insulated joint in the side of the cylinder. The heavy current leads were joined, one to the insulated electrode, the other to the side of the brass cylinder itself. Two inlet tubes, one joined to a vacuum pump, the other through purifying vessels to a hydrogen generator, completed the essential parts of the furnace chamber.

For the resistance tubes both carbon and Acheson graphite were used, the latter being more easily machined and making better contact with the terminals, though the necessity for thinner walls made them more fragile than the carbon tubes. The length of the tubes used was 15 to 20 cm, and they were bored out with a hole 4 mm in diameter. The original outside diameter of 16 mm was left for a length of about 15 mm at each end for the contact and the wall filed down between these points to a thinness sufficient to give the necessary resistance, this requiring a wall only about 0.5 mm thick for the graphite tubes with the available power. The heating current was supplied by a 5 K. W. transformer kindly loaned by Professor Cottrell of the Department of Physical Chemistry. This transformer could be connected for different voltages in the secondary, the connection generally used giving about 25 volts when supplied from the 110-volt circuit. The primary current in the transformer was regulated by a rheostat, enabling the heating current to be gradually raised to the maximum output.

The hydrogen used to fill the chamber was generated from zinc and sulphuric acid, and purified by passing through a series of vessels containing sulphuric acid, alkaline pyrogallic acid, and sodium hydroxide.

The photographic observations were made with a small quartz spectrograph, Seed's orthochromatic plates being used. A quartz lens was employed to project an image of the interior of the furnace tube on the slit.

Method of work.—If the substance to be placed in the tube absorbed water readily, all water was first driven off by heating in a porcelain crucible. Then the substance was transferred to the tube which was

kept heated by the current almost to red heat. The chamber was closed as quickly as possible and pumped out to a pressure below 1 cm, sometimes as low as 1 mm. Hydrogen was then passed slowly in and pumped out, the chamber being flushed out several times with the gas and finally allowed to stand full of hydrogen at atmospheric pressure. The heating current was then turned on and the primary resistance gradually decreased until the full voltage of the transformer was on the tube, and the exposure made, a current of nearly 200 amperes then passing through the tube. As the pressure of the hydrogen increased with the heating of the tube, a stopcock connecting with the water-jet pump through sulphuric acid vessels was opened from time to time keeping the hydrogen in the chamber always somewhat above atmospheric pressure.

When the fragile graphite tubes were used, the current was usually allowed to run until the tube broke, this taking place, in cases where there was no vigorous action between the substance being vaporized and the material of the tube, after a run of 15 to 30 minutes, owing to stresses caused by the unequal expansion of the tube and the supports by which the current was led in. The window at the opposite end from that toward the spectrograph could be used at any time for visual observations by placing a direct-vision spectroscope in front of this window. This was especially useful for watching the change in the spectra at different stages of the run.

RESULTS

Sodium.—The observations made with sodium in the tube gave important data both on the part played by chemical action and on the lines given under the conditions present in the furnace. Only visual observations were possible with metallic sodium in the tube, as the tube disintegrated so rapidly under the action of the sodium that no time for a photographic exposure was allowed after the furnace reached maximum heat. With the limited chemical action here present, the D lines did not appear readily, in spite of the large amount of sodium vapor in the tube. They appeared, however, as only moderately strong bright lines when the tube reached brightest incandescence.

With carefully dried sodium chloride in the furnace, the action on

the material of the tube was much slower and it was possible to photograph the spectrum. A preliminary visual observation showed that the chloride gave the D lines under these conditions better than the pure metal. The lines appeared readily as the tube became hot and remained as strong bright lines.

A photograph was obtained with sodium chloride in the tube which confirmed the visual observations as to the strength of the D lines given by the salt and showed a number of other sodium lines whose identification in the visual observations was rendered uncertain by the small dispersion used. The following pairs of lines appear on the plates. The intensity numbers indicate roughly the intensities of the pairs, the component lines being so close together as to render difficult a judgment of their separate intensities.

λ	Intensity	λ	Intensity
6161.15, 6154.62	6	4669.4, 4665.2	trace
5896.16, 5890.19	60	3303.07, 3302.47	16
5688.26, 5682.90	8	2852.91	4
4983.53, 4979.30	2		

Two interesting points may be noted for this spectrum: (1) Three members of the principal series, viz., λλ 5896–90, 3303–02, 2853, are given very strong under conditions which *exclude the presence of any appreciable supply of oxygen.* This contradicts the view held by some investigators that these lines require the presence of oxygen; although, as has been noted, it is probably true that chemical action, such as that afforded by the dissociation of a sodium salt, greatly favors the production of these lines. (2) A comparison of this list of lines with that given by de Watteville[1] of flame lines of sodium shows that he obtained with the flame the lines listed above (except the pair λλ 6162–55, out of the range of his photographs) and no others, in spite of the vigorous chemical action taking place in the flame. Furthermore, the relative intensities of the pairs as given by the furnace are surprisingly close to those of de Watteville's plates, the

[1] *Phil. Trans.*, **204**, 139–168, 1904.

latter giving intensities 50, 8, 4, 2, 10, 5, for the six pairs beginning with λ 5896. He found these lines of about the same intensity in both the cone and the outer portion of the flame used.

Calcium; line spectrum.—The following calcium lines were photographed distinctly with metallic calcium in the furnace tube in an atmosphere of pure hydrogen:

5594.64	4435.86
5588.96	4425.61
5270.45	4226.91
4456.08	

Of these lines, λ 4227 was very broadly reversed. Traces could be detected of the group of six lines from λ 4319 to λ 4283. Nothing was to be seen of $\lambda\lambda$ 3968, 3933 (H and K of the solar spectrum) which are strong in arc, spark, and sun.

A remarkable phenomenon is to be noted in regard to the lines H and K. Although they did not appear with this large amount of pure calcium present, they were given faintly on two plates when calcium (probably some compound) was present only as an impurity. One of these plates was taken with caesium chloride in the furnace tube, the other with mercuric chloride. In both cases λ 4227 is given strong but not reversed, and the H and K lines may be seen distinctly, coinciding exactly with the same lines in comparison arc spectra.

Although this behavior of H and K requires further investigation before an explanation can be offered, it may be mentioned here that the lines appear faintly in the more intense flames and traces of them were obtained by the author in a previous investigation,[1] when calcium was vaporized in a carbon tube heated by an arc on the outside, air being present. It thus appears that the temperature of the furnace will not give these lines unless some chemical action takes place which is not permitted when pure calcium is vaporized in an atmosphere of hydrogen. Aside from the absence of the H and K the furnace in hydrogen gives a spectrum not very different as regards the lines which appear and their relative intensities from the flame spectrum observed by de Watteville[2] and by Olmsted[3] and that of the arc furnace in air.

[1] *Astrophysical Journal*, **21**, 236–257, 1905.

[2] *Loc. cit.*, p. 152.

[3] *Bonner Dissertation*, 1906.

Band spectrum.—Bands were photographed in the orange, yellow, and green which appear to coincide in position with the flame bands at λλ 5934, 5816, and 5543, ascribed by Eder and Valenta[1] to the chloride and oxide. As these compounds were absent in the furnace, the bands which appear must belong to the metal itself or to the carbide or hydride. A rich band spectrum was also observed visually in the red, for the definite location of which a higher dispersion will be necessary.

Iron.—A large number of iron lines were given by the metal in the furnace tube. This was probably as near a "temperature spectrum" as any that were obtained in the hydrogen atmosphere, there being no perceptible chemical action on the iron unless a slight adhesion to the graphite of the molten iron which was not vaporized indicated the formation of a carbide.

On account of this minimum chemical action, it is of interest to compare the list of lines given by the furnace with those obtained by de Watteville[2] from the iron flame, the temperatures of the two sources being not very different, while in the flame the chemical processes have full scope. The following table gives the estimated intensities of the iron lines on my plates, and in the next two columns the intensities given by de Watteville of the same lines as they appeared respectively in the cone and exterior portion of the flame used by him.

The following table permits only a very rough comparison between the spectra of the furnace and flame, as the photographs were made by different observers under widely different experimental conditions. Many more lines are recorded by de Watteville than are given on my plates, but this does not give a comparison of the actual richness of the two spectra, as the furnace tube usually broke after a run of 20 to 30 minutes, while exposures as long as eight hours were used by de Watteville for the flame. In general, however, the results speak strongly for the spectrum of the flame being due very largely to temperature radiation, since the lines given by the furnace in hydrogen are found not only in the cone of the flame, but in the large majority of cases in the external layers where chemical action should be at a maximum. There are, to be sure, many differences in rela-

[1] *Beiträge zur Photochemie und Spectralanalyse*, p. 92.

[2] *Loc. cit.*, pp. 164–168.

λ	Furnace in Hydrogen	Flame Spectrum (de Watteville)	
		Cone	Flame
5434.66	8	2	..
5429.74	8	1	..
5397.27	6	2	..
5371.62	5	4	3
5328.15	10	5	4
5270.43 } 5269.65	10	6	5
5167.50	4	1	..
4528.78	9	3	..
4443.30 } 4442.46	4	2	..
4427.44	6	8	6
4415.27	7	7	1
4404.88	8	9	4
4383.70	15	10	6
4325.92	7	9	5
4307.96	8	8	5
4271.93 } 4271.30	1	8	6
4260.64	7	7	1
4250.93 } 4250.28	2	5	2
4222.32	1	3	..
4219.47	2	2	..
4134.77	1	4	..
4132.96	1	1	..
4067.36 } 4067.04	2	2	..
4063.63	3	10	5
4058.30	4	1	..
4045.90	20	15	7
3969.34	1	8	trace
3923.00	10	10	10
3920.36	9	10	10
3899.80	2	9	9
3895.75	6	9	9
3886.38	10	12	12
3878.82 } 3878.12	8	10	10
3860.03 } 3859.34	18	10	10
3841.19 } 3840.58	2	7	3
3827.96	10	7	2
3763.90	2	6	3
3758.36	2	7	4
3749.61	12	8	4
3737.27	12	8	8
3720.07	10	8	8
3705.70	4	8	8
3687.58	1	6	3
3647.99	1	7	5

λ	Furnace in Hydrogen	Flame Spectrum (de Watteville)	
		Cone	Flame
3631.62	1	8	5
3618.92	1	8	5
3608.99	1	8	5
3581.32	2	8	8
3570.23	2	9	7
3497.92	1	7	6
3490.65	1	8	8
3476.75	1	7	7
3475.52	1	8	8
3465.95	1	8	8
3441.07 } 3440.69 }	5	10	10

tive intensity of lines, which may be due both to the differences in temperature and to the chemical processes in the flame.

At the Mount Wilson Solar Observatory I have had an opportunity to compare these results for the iron spectrum with the intensities of iron lines in the spectra of the sun and of sun-spots. The lines given strongly by the furnace in the yellow and green are without exception lines much intensified in sun-spots. This relation does not hold so generally for lines in the violet and the beginning of the blue, a condition found by Messrs. Hale, Adams and Gale[1] to hold for other light-sources in which the temperature was comparatively low. As furnace spectra with more efficient apparatus and higher dispersion will probably soon be obtained in the observatory laboratory, it will perhaps not be profitable in this paper to go farther into the astrophysical side.

Copper.—With the metal in the furnace, the only copper line obtained was the flame line λ 5105.75. The same groups of bands appear which were observed by the author with the arc furnace and which have also been obtained in the flame. These bands have heads at λλ 4005, 4280, 4499, 4547, 4598, 4649, 4689. With the tube furnace in hydrogen, the formation of either a carbide or hydride is possible, but the first of these compounds is unlikely in the oxy-hydrogen flame, and the second could scarcely appear in the arc

[1] *Contributions from the Solar Observatory*, No. 11; *Astrophysical Journal*, **24**, 185–213, 1906.

furnace without hydrogen atmosphere. It thus seems probable that these copper bands are due to the metal itself.

Mercury.—Several attempts were made to obtain the mercury spectrum by forcing the furnace to its maximum temperature, but no lines were obtained. Observers of the flame spectrum have had the same experience. Mercury placed in the furnace tube was of course quickly vaporized and might not be sufficient for the purpose, so a large supply of the vapor was provided by placing a crucible of the liquid immediately beneath the furnace tube. A good deal was also lying on the bottom of the brass chamber. The furnace was then given a long run at maximum current. The furnace chamber around the tube became hot enough to melt lead on the outside, and the mercury was vaporized in large quantities, condensing thickly over all parts of the interior when the apparatus cooled. The furnace thus ran in an atmosphere of mercury vapor saturated at a high temperature, but no spectrum appeared.

Mercuric chloride was tried in the hydrogen atmosphere. It was thought at one time that the green mercury line was observed visually, but the low dispersion made this uncertain and it was not confirmed by the photographs.

Caesium.—The chloride was used in the furnace tube, but the conditions were not so favorable as in the author's former work with the arc furnace, only the pair $\lambda\lambda$ 4593, 4555 appearing faintly on the plates. Probably the small amount of the salt in the tube would account for this weakness of the spectrum, as with the arc furnace a large quantity of the chloride was fed into the tube as the experiment progressed.

As has been noted, this spectrum as well as that of mercuric chloride was notable in that it showed the H and K lines of calcium.

SUMMARY

The results of this investigation may be summarized briefly under two heads: (1) There is no evidence to indicate that a sufficiently high temperature will not produce radiation without the intervention of either electrical or chemical action, although when chemical action was permitted the radiation appeared to be favored thereby; (2) the similarity of the furnace spectra to those given by

the more intense flames indicates that the radiation of the flame is very largely a thermal effect, aided without doubt by the abundant chemical processes attending the combustion.

These experiments were carried out in the physical laboratory of the University of California, and I wish to express my thanks to Professors Slate and Lewis for the facilities placed at my disposal.

PASADENA, CAL.
March 1908

SOME REMARKS ON PROFESSOR BARNARD'S ARTICLE ON *SATURN'S* RINGS

By W. H. WRIGHT

In the January number of the *Astrophysical Journal* Professor Barnard has published an exceedingly interesting account of his observations of *Saturn's* rings during the recent opposition. He has also added an explanation of the bright "beads" or "knots" observed on the rings when we view their unilluminated surfaces. At the time of reading Dr. Barnard's article I had in the process of preparation for publication some notes on the same subject, that is, in explanation of these phenomena, the theory, like that of Barnard's, being based, partly at least, on the meteoric constitution of the rings. So far as I am aware Professor Barnard's paper contains the first published discussion of the phenomena presented by the "disappearance" of the rings, treated in the light of our knowledge of their meteoric constitution, it being a curious fact that even recent discussions of the subject have been based upon the assumption that the rings are opaque. My conclusions differ in some respects, however, from those of Barnard, and it appears worth while to make some statement of them; but as much that I had in mind to say has been said by him, I shall, to avoid repetition, put my remarks in the form of comments on his article.

Professor Barnard states that since the rings are made up of meteorites we should expect that they would be visible from the unilluminated side by the "percolation, scattering, and reflection of sunlight through them," and on this ground he endeavors to explain the visibility, not only of the crape ring, but of the entire system, including the outer beads. To quote directly from the article:

> We should therefore expect to see the entire surface of the rings at this time by percolation, scattering, and reflection of the sunlight through them. One might expect under these conditions that the brighter portions of the ring wouldappear dark when so seen by cutting out more of the sunlight through a greater number of particles. This, however, up to a certain point of density would not be so; it would in reality be just the reverse. In the case of the crape ring it would appear faint—as it does always—because of the fewer particles to reflect the sun-

light. Were they more densely packed, as in the bright rings, there would be a relatively greater amount of scattering, reflection, and diffusion of the light and they would appear relatively bright.

It is apparent to any observer of *Saturn* ordinarily, with a telescope of sufficient power, that the outer one-fourth of the inner bright ring is much the brightest part of the entire ring and ball system; the inner portion of that ring being of the same brightness as the outer ring, which is uniformly illuminated. Let us therefore see where these condensations fall on the projection of the rings.

As regards the visibility of the crape ring it seems to me that Professor Barnard's statement is correct. In fact he might have gone farther and said that the crape ring would appear intrinsically brighter viewed from the unilluminated side at a low angle with the surface than it does when seen from the relatively high angle at which it is observable from the other side. It seems not improbable that when viewed at a grazing angle its intrinsic brightness is, in places, probably half that of the brightest part of the system. This increased brightness is due to the fact that the lower the angle of observation the more meteorites, of which the ring is composed, are included in a given small solid angle of vision, and therefore, up to a certain point, the brighter the thin projection of the ring should appear.

Considering now the visibility of the denser part of the ring system from the unilluminated side, due to light coming through it, the explanation seems to me to be at least doubtful; while it appears very improbable that any illumination as strong as that involved in the outer beads could be due to this cause. Let us assume that the ring system is solid. In that case we, on the unilluminated side, would get no light except that coming from the edges. If we now conceive the ring to be composed of closely packed, independent bodies, we shall still get no light, provided the bodies are close enough together. If a number of these bodies, or meteorites are removed, here and there, through the mass, some of the remaining ones will finally be seen illuminated, and as the process of removal proceeds, the amount of light so given out will increase up to a point where the bright meteorites are relatively so numerous that their removal takes away more light than is added by the elimination of those which cast shadows on others in the field of view. Beyond this point the elimination of meteorites will act only to cause less light to reach us from the rings, which will consequently decrease continuously in brightness to the point of extinc-

tion. There is nothing about the problem to warrant the belief that there is a double maximum of light during the process of thinning out. Applying these considerations to the question in hand, it appears that if the meteor density is such in one zone of the crape ring as to give a maximum of light, or bead, as seen in projection, this light falling away as the denser middle ring is approached, we cannot expect a further increase in density, such as we find in the outer part of the middle ansa, to result in a second maximum, unless we assume entirely different plans of distribution of the meteorites in the two places. In fact it is difficult to see how any light can be transmitted through the denser portions of the ring, in view of the degree of opacity which we are bound to attribute to the rings as a result of Barnard's observation of the eclipse of *Japetus*.[1] This observation, it will be recalled, consisted in estimating the brightness of the satellite while it was undergoing eclipse by the rings. As the satellite passed through the shadow of the crape ring, its light gradually faded away, to become rapidly extinguished when it entered the thickening shadow of the middle ring. At the time of this observation (November 1, 1889) the sun was shining upon the plane of the rings from an angle of elevation of $11°10'$. The observation showed that the fainter parts of the middle ring are opaque for this angle of incidence, and it may reasonably be concluded that both the bright rings are equally so throughout their entire extent. The bright beads were visible on October 19, 1907, on which date the angle of elevation of the sun was $1°17'$. A ray of sunlight striking a particle on the dark surface would have to traverse a path within the medium composing the rings many times longer than that which was, or rather was not, traversed during Barnard's observation of the eclipse, the exact ratio being $\frac{\sin 11° 10'}{\sin 1° 17'}$, or 8.6. The absorption in the denser part of the middle ring would be correspondingly greater, and it would seem impossible that the amount of light seen in the outer beads could filter through such a region.

Bond sought to account for these phenomena on the basis of an opaque system, considering the outer beads to be the edges of the two bright rings seen through the Cassini division, and as the rings are

[1] *Monthly Notices*, 50, 107, 1890.

practically opaque, it seems worth while to examine this suggestion somewhat critically. Bond's theory of the inner beads is weak, inasmuch as he assumes, for the purposes of his explanation, a division between the middle and crape rings, an assumption which is not tenable in view of Barnard's observation of the eclipse of *Japetus*. It is to be noted that, if his explanation of the outer knots is correct, a relation must be satisfied between the width of Cassini's division, the thickness of the ring system, and the position of the beads; or, to put it differently, if we assume the explanation to be the true one, we can form some idea of the thickness of the rings. The following rough computations were made before Professor Barnard's paper was published, and are based on Professor Aitken's measures published in *Lick Observatory Bulletin*, No. 127. In taking the mean of his results I have omitted the first observation of November 2, as it seems to have been affected by peculiar conditions. The means are as follows:

Date	1907, November 6.8
Distance of preceding outer knot from limb of planet	$8''.376$
Distance of following outer knot from limb of planet	8.145

These distances, reduced to the mean distance of *Saturn* from the sun, are respectively $7''.844$ and $7''.628$, or referring the positions of the knots to the center of the planet[1] we have

Distance of preceding knot from center of planet	$16''.74$	reduced to mean dist. of planet from sun.
Distance of following knot from center of planet	16.53	
Mean	$16''.64$	
Difference	$0''.21$	

Suppose the planet to be close to opposition. Let $\odot$ represent the elevation of the sun on the south side of the plane and $\oplus$ that of the earth above the other, then (Fig. 1) if D be such a point that

$$ID\,(\tan\odot+\tan\oplus)=t\,, \qquad (1)$$

where t is the thickness of the ring, the edge of the outer ansa will be visible partially at least between A and D, while that of the middle ansa will show between H and F, the line DF being directed toward the observer. If we could determine the position of the point D

[1] Barnard's measures of the system of *Saturn* (*Monthly Notices*, 56, 171, 1896) have been used throughout this discussion.

we could compute t at once. The illumination at D and F is slight, as the illuminated parts of the exposed edges are points at these places. I have therefore assumed that the point D is twice as far to the right of the center of intensity of the bead as A is to the left. We have then:

Radius outer edge of Cassini's division	$17''.52$
Mean distance of knots	16.64
Probable distance out of inside edge of knots	14.88

Let

$$DCA = \theta^o \text{ and } ICA = \theta^i,$$

then

$$\cos \theta^o = \frac{14.88}{17.52}$$
$$\theta^o = 31^\circ\ 50'.$$

Similarly

$$\theta^i = 28^\circ\ 53'.$$

ID is therefore readily computed and equation (1) gives

$$t = 0''.042\,,$$

which corresponds to a thickness of slightly less than 180 miles.

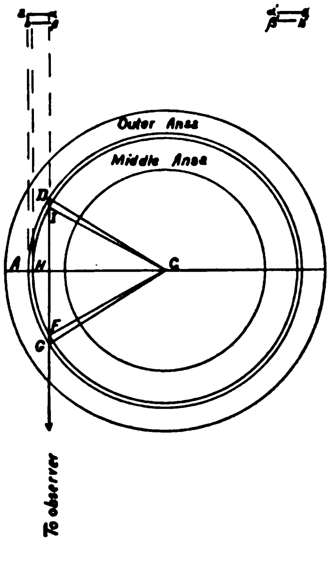


FIG. 1

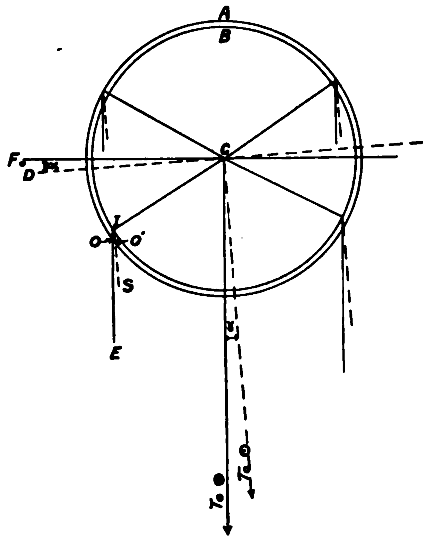


FIG. 2

For convenience let the bright edges AD and HF as seen in projection be represented by $a\alpha$ and $b\beta$ respectively, $\alpha'a$ and $\beta'b$ being the corresponding edges on the outer side (Fig. 1, upper part). If,

as has been presumed, the planet is at opposition and the rings are of uniform thickness throughout, the points α, β, α' and β' are all equidistant from the center. Suppose now the sun to move to the right as indicated in Fig. 2. Under these conditions the symmetry of illumination is destroyed, with the result that the points α and α' (Fig. 1) will move to the left, while β and β' go to the right. To determine the amount of these motions, let I be the point on the periphery of ring B which corresponds to the new position of β. Let IE be drawn toward the earth and IS toward the sun. Designate by O and O' the points where these two lines cut the inner edge of ring A, draw CF through the center perpendicular to IE and CD perpendicular to IS. Further let

$$a = FCD\text{[1]},$$
$$\phi^i = ICF,$$
$$\phi^o = OCF,$$
$$\Phi^i = ICD,$$
$$\Phi^o = O'CD,$$
$$\rho_1 = CI,$$
$$\rho_2 = CO.$$

then

$$t = IO' \tan \odot + IO \tan \oplus,$$
$$IO' = \rho_2 \sin \Phi^o - \rho_1 \sin \Phi^i,$$
$$IO = \rho_2 \sin \phi^o - \rho_1 \sin \phi^i,$$
$$\phi^i = \Phi^i + a,$$
$$\frac{\cos \phi^o}{\cos \phi^i} = \frac{\rho_1}{\rho_2} = \frac{\cos \Phi^o}{\cos \Phi^i}.$$

These equations serve for the determination of $\phi^i = ICF$, the solution being effected by trial. The shift of β (Fig. 1) to the right, which we shall call δ_β, may then be readily obtained from the expression

$$\delta_\beta = \rho_2(\cos \phi^i - \cos \theta^i).$$

The displacements of each of the points α, α', and β' may be obtained by a set of equations similiar in form to the above group. The values determined, using Barnard's constants of the system, are

$$\delta_\beta = +0''.50,$$
$$\delta_\alpha = -0.30,$$
$$\delta'_\beta = +0.30,$$
$$\delta'_\alpha = -0.51,$$

[1] This is the angle between the earth and sun measured in the plane of the rings. The value for November 6.8, 1907, as determined graphically with sufficient accuracy for present purposes, is $3^\circ.95$.

where δ'_β and δ'_α are the displacements of β' and α' respectively. If the edges of the two rings were equally bright, we should expect the knots, due to the superposition of the bright lines on either side of the planet to maintain the symmetry of their positions with respect to the planet, but as the outer edge of ring B is much brighter than the inner edge of A the predominating motion in each knot must be toward the right from such a position. Further, the left-hand or following knot should be the brighter of the two. The amount of the dissymmetry introduced would be dependent on the relative brightness of the two edges, and also, to a great extent, on the relative thickness. In fact, if we suppose the bright outer edge of ansa B to be only slightly thicker than the inner edge of A, which is much the fainter of the two, the motion of the knots will be governed almost entirely by the motion of the points β and β'. The actual difference in the distances of the knots from the center, as observed by Aitken, is $0''.21$, the following knot being brighter and closer in.

It will be seen that the effect of the side illumination of the rings, as shown in Fig. 2, is to bring the beads closer together than they would be were the planet at opposition, and that this should have been allowed for in computing the thickness of the ring. Equation (1) by which t was computed is based on the supposition that the planet is at opposition, while the quantities which we substituted in it were obtained from measures made while the conditions indicated in Fig. 2 obtained. The value of t determined above should therefore be slightly increased, and may be put at about $0''.05$, a quantity which agrees better with Barnard's measures of the outer beads.

It may be remarked that a very good test of Bond's theory, as elaborated above, would be afforded by a complete set of measures of the knots, covering a larger range of values of the angle $(\odot + \oplus)$ taken without regard to sign. As this value increases, the knots should approach the planet, while if they are due to anything fixed on the rings their positions should remain constant. Barnard states that they have remained fixed throughout his observations, but it should be borne in mind that the quantities involved are small, and the observations to be determinative should be considered with reference to the angle $(\odot + \oplus)$. Barnard's measures put the knots $0''.20$

closer in than do those of Aitken, and the difference may be due to some such cause.

The foregoing comments are made, not in the belief that Bond's theory of the outer knots has by any means been proved, but merely to call attention to the fact that it accounts in a fairly satisfactory way for the phenomena observed, and may possibly furnish an independent means of determining the thickness of the ring system.

In closing I may be permitted to suggest the necessity of considering many of the phenomena presented by *Saturn's* rings in connection with the relative positions of the earth, the sun, and the plane of the rings. It may readily be shown, for instance, that an extensive body of meteoric stones, most of which are large enough to cast shadows, may appear much brighter when exactly at opposition than when viewed from slightly to one side of the path of incident light, the increase being dependent, to a certain extent, on the density of the swarm. It would therefore be of interest to learn whether any variation in the relative intensities of different parts of the ring system occurs when the planet approaches a point directly opposite the sun. For the exact realization of such a condition opposition must, of course, occur when the planet is at the node, though an opposition close to that position would doubtless suffice for the observation. It might also be worth while to note whether the crape ring is intrinsically brighter when the rings are narrow than when they open out, care being taken to allow for very obvious physiological effects tending to influence such an observation. In this connection the fact may be significant that the crape ring was independently discovered by three observers just as the system was opening out. It is not impossible that the increased amount of material which we must look through when the rings are narrow would cause what is ordinarily the outer zone of the crape ring to appear to be the inner one of the middle ring; in other words, the inner diameter of the middle ring may vary with the inclination of the rings to the line of sight. The writer is led to make these suggestions in view of the numerous changes reported in the appearance of the rings by many observers.

Dr. Barnard makes the suggestion that the rings are self-luminous, but dismisses it with the statement that such a theory is not in keeping with the physical constitution of the rings. While this explanation is

perhaps not the most probable one, still it does not appear as though it should be thus summarily disproved of. It is not unlikely that there is, in the aggregate, a great amount of friction, collision, etc., between the bodies composing the system, and the heat thus generated might be sufficient to cause the feeble luminosity observed, both over the surfaces of the two dense rings, and in the knots.

MT. HAMILTON
March 1908

FUNDAMENTAL SPECTRUM

SUN, APRIL 12, 1907

$W = 27.4$ $V_0 = 0.50$ km

Region	λ	s	Region	λ	s	Region	λ	s
1.....	4020	683	8.....	4235	822	15.....	4490	997
2.....	4034	693	9.....	4270	845	16.....	4524	1019
3.....	4062	710	10.....	4296	864	17.....	4546	1036
4.....	4112	742	11.....	4335	889	18.....	4596	1070
5.....	4138	759	12.....	4380	920	19.....	4641	1102
6.....	4168	780	13.....	4406	938			
7.....	4197	798	14.....	4452	970			

$\log \Sigma \frac{1}{s}$

Region	14	15	16	17	18	19
1..........	8.24022	8.26458	8.28717	8.30829	8.32779	8.34592
2..........	8.20202	8.22855	8.25305	8.27584	8.29682	8.31626
3..........	8.16077	8.18985	8.21656	8.24130	8.26397	8.28490
4..........	8.11631	8.14842	8.17771	8.20469	8.22930	8.25193
5..........	8.06900	8.10466	8.13694	8.16649	8.19329	8.21783
6..........	8.01720	8.05717	8.09304	8.12561	8.15497	8.18067
7..........	7.96009	8.00539	8.04560	8.08178	8.11414	8.14342
8..........	7.89592	7.94802	7.99361	8.03419	8.07015	8.10243
9..........	7.82295	7.88394	7.93636	7.98236	8.02268	8.05854
10..........	7.73791	7.81104	7.87239	7.92526	7.97095	8.01115

Two of the plates were two-prism spectrograms. The card of data for the fundamental spectrum has the same form as above.

Plate	Date (G.M.T.)	Exposure	Observer	v	n	v_c	O−C
	1906			km		km	km
IB 872	Oct. 1.787	75^m	B.	+11.93	17	+12.02	−0.09
912	Nov. 9.589	105	B.	+38.44	8	+37.53	+0.91
IIB 87	Nov. 23.544	184	F.-B.	−22.68	12	−20.72	−1.96
90	Nov. 24.553	210	F.-Fox	+39.03	12	+39.17	−0.14
IB 917	Nov. 27.514	101	F.-B.	−24.31	16	−25.11	+0.80
919	Dec. 1.542	92	F.-Fox	−19.57	17	−20.08	+0.51
921	Dec. 3.610	92	F.-Fox	−19.22	17	−19.20	−0.02
951	Jan. 25.531	90	B.	+30.44	14	+31.34	−0.90
	1907						
1164	Sept. 13.872	130	F.	+42.58	9	+43.19	−0.61
1170	Sept. 21.787	133	F.-B.	+16.93	15	+17.86	−0.93
1215	Oct. 20.696	120	F.	− 6.56	17	− 8.48	+1.92
1244	Nov. 23.592	100	Lee	+42.67	12	+42.18	+0.49
1249	Nov. 25.601	120	Lee	+39.62	9	+39.65	−0.03
1255	Nov. 27.610	82	Fox-B.	+33.14	13	+35.66	−2.52
1259	Nov. 30.604	120	Fox	− 2.85	17	+ 0.43	−3.28
1264	Dec. 4.571	180	Fox	+19.14	16	+18.99	+0.15
1273	Dec. 6.503	112	Fox-F.	+31.15	16	+30.98	+0.17
1277	Dec. 6.701	140	Fox	+14.21	13	+14.56	−0.35

The data for the eighteen spectrograms measured are given in the journal of observations. I need perhaps say that, because of the short period of the star, the dates were later corrected for the light-equation. In the column giving the observer, F = Frost and B = Barrett. Mr. Sullivan assisted in guiding for all of the plates. In column n are recorded the number of regions compared for each plate.

Using Schwarzschild's method I have found the following elements:

$$U = 2.0818 \text{ days}$$
$$\omega = 223^\circ.1$$
$$e = 0.062$$
$$\mu = 172^\circ.9276$$
$$T = J.D.\ 2417484.482$$
$$a \sin i = 981460 \text{ km}$$
$$K = 34.35 \text{ km}$$
$$V = 10.5 \text{ km.}$$

I give, for convenience of reference, Aitken's recently published[1] elements of the visual binary *13 Ceti:*

$$P = 7.42$$
$$T = 1905.28$$
$$e = 0.74$$
$$a = 0''.214$$
$$\omega = 51^\circ.75$$
$$\Omega = 50^\circ.40$$
$$i = \pm 48^\circ.05$$

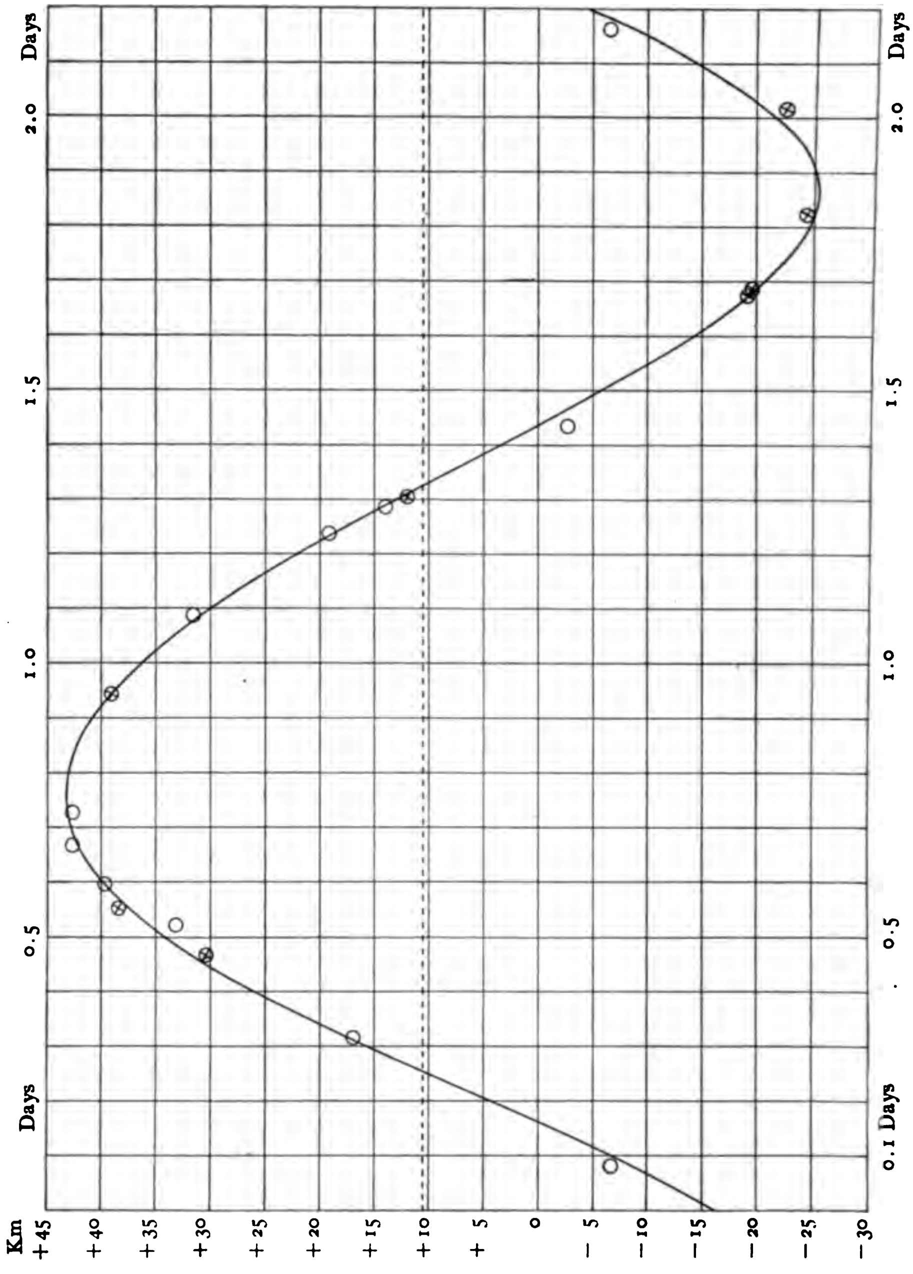
Angles increasing.

As the spectroscopic system is moving about the center of mass of the visual binary in an ellipse of great eccentricity, there may have been a sensible change in its velocity between the autumn of 1906 and of 1907. This change may have been large enough to affect considerably the elements given above. In the accompanying velocity-curve computed from the elements given above I have indicated the observations for 1906 with crossed circles. For neither year was the number of observations sufficient for a separate determination of the orbit.

When the parallax of the star is known, the relative radial velocities of the visual companions can be computed by the formula of Lehmann-Filhés.[2]

[1] *Lick Observatory Bulletin,* 110, January 24, 1907.

[2] *A. N.,* No. 3332, 139, 308, 1896.



VELOCITY-CURVE OF *13 Ceti* WITH OBSERVED POINTS

$$K=\frac{R}{864000\sin\pi}\frac{a''}{p''}\frac{\mu\sin i(\cos u+e\cos\omega)}{\sqrt{1-e^2}}\;.$$

Assuming a parallax, $p''=0\overset{''}{.}01$, the relative radial velocities for the two years are as follows:

Epoch	t	v	K	ΔK
1906.89..................	1.61 yr	152°.9	42.8 km	12.4 km
1907.85..................	2.57	167.1	30.4	

If the components are of equal mass we would need to displace the second set of observations up or down[1] on the velocity curve by 6.2 km. In view of the large proper motion of *13 Ceti*, given by Auwers as $0\overset{''}{.}397$, the parallax is probably greater than $0\overset{''}{.}01$. In the distribution of masses in the system the brighter component, the spectroscopic binary, probably takes the larger part. Presumably, then, the variation in the radial velocity, ΔK, of the spectroscopic system between these years is considerably less than 6.2 km and is probably insensible.

Of the various perturbations which the third body will produce on the spectroscopic binary some will probably be great enough to be appreciable. The period, U, should be noticeably longer at periastron than it is now, when near apastron. The great eccentricity of the visual orbit will be a powerful factor here. It may be possible to detect the revolution of the line of apsides, although this may be masked on account of the small eccentricity of the spectroscopic orbit. However, there may be a considerable change in the eccentricity. It will be essential for a study of the perturbations to secure plates at several epochs for separate determinations of the spectroscopic orbit.

I hope to secure enough plates in the autumn of 1908 to make a new determination of the orbit. The spectroscopic binary will then be at the apastron of the visual orbit, 1908.99, and the period will be at its minimum. The following year, at 1909.98, the motion will be parallel to the line of nodes and the observed velocity of the spectroscopic binary system will be the radial velocity of the visual system. In 1912.58 the spectroscopic binary will pass the node

[1] The sign is not yet determinable.

nearest periastron, whether ascending or descending is as yet unknown, and the visual components will have their maximum relative radial velocity. In 1912.70 it will be at periastron and will have its maximum period. In 1912.87 it will again be moving parallel to the line of nodes and the visual components will have zero relative radial velocity. In 1913.44 it will again cross the line of nodes. In moving the 180° between $\omega+v=0°$ and $\omega+v=180°$, accomplished in 0.86 year, the change in relative radial velocity of the components of the visual system is very rapid and plates for a determination of the orbit must be secured within an interval of a few days. It will eventually be possible to correct each observation for the motion of the spectroscopic binary system. It may be that to assure the necessary number of plates for a determination of the orbit at such a critical time as the periastron passage, the co-operation of other observers must be sought.

I wish in conclusion to acknowledge my indebtedness to Professor Frost for his advice and assistance in the investigation of this orbit.

YERKES OBSERVATORY
April 17, 1908

NOTE ON THE PHOTOGRAPHY OF VERY FAINT SPECTRA

By R. W. WOOD

It is a well-known fact that photographic plates require the action of a certain amount of light before any image can be developed, or rather that a plate can be exposed for some little time to a very dim light and still yield no image. It has been proposed on this account to fog plates slightly which are to be used for securing records of feebly illuminated objects, by a preliminary exposure to a very feeble light, but so far as I know the method is not generally used. Having recently used it with very great success, I think that it is worth bringing anew to the attention of those engaged upon the work of photographing weak spectra. In the work upon which I am now engaged, the photography of the resonance spectra of sodium vapor, excited by monochromatic radiations, with a large concave grating, exposures of twenty-four hours are necessary, and even then many of the lines are so faint as to be barely discernible on the plate. I am convinced that the action can be doubled, or the exposure time necessary to secure a given result cut in half, by a judicious use of the method.

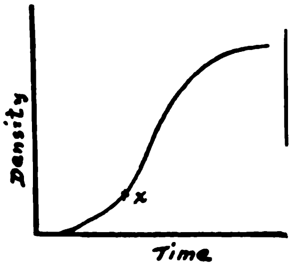


FIG. 1

As is well known, the curve representing the action of the light on the plate with the time is of the form shown in Fig. 1, the darkening of the plate being represented by the ordinates, and the times of exposure by abscissae. Preliminary exposure to feeble light carries the plate to the point where the curve begins to rise rapidly (x), and it is obvious that the exposure to the faint spectrum should be made to come on this part of the curve. It is first necessary to find out just what exposure is necessary to bring about this result. This can be done in a few minutes in the following way. A gas flame is turned down until the yellow tip is only three or four mm high, and a plate held at a certain distance from it, covered with a sheet of

black paper. The paper is now drawn aside step by step, exposing the plate in sections, the steps being made every two seconds. The plate is now developed, care being taken to push the development as far as possible.

Personally I favor glycin, and develop for fifteen or twenty minutes in a rather strong developer. By counting the number of strips which appear on the plate, it is possible to determine how long the exposure must be to secure a given action. I find that the best results are obtained by giving an exposure which will yield a faint image, say the time given for the recording of the second strip. A little experimenting is of course necessary before the best results are

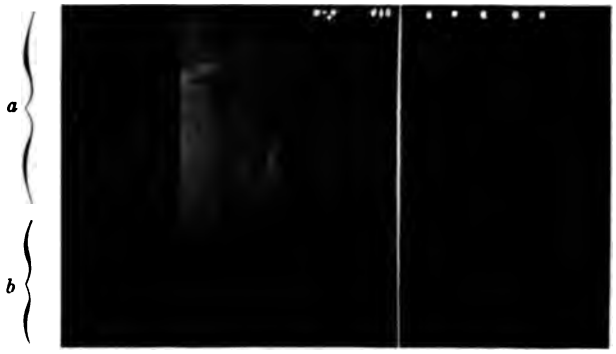


FIG. 2

secured. With a flame of the size described, this time is four seconds with the plate at a distance of about two meters. It is immaterial whether this exposure is made before or after the exposure of the plate to the spectrum.

I tested the method in the following way, and any experimenter can convince himself of the gain derived, by repeating the experiment. A nitrogen vacuum tube was placed in contact with the slit of a large three-prism spectrograph, great care being taken to secure an even illumination of the entire slit. The plate was exposed for five minutes, which was known to be far too short a time for securing a satisfactory record of the bands. After the exposure the plate was removed from the holder and the lower half covered with black paper. The upper half was then exposed to the small gas flame for

four seconds, and the plate developed to its utmost limit. The resulting picture is reproduced in Fig. 2, the portion "*a*" being the part which received the subsequent illumination. In the portion "*b*," which was screened, there appears only one strong line and a trace of the head of the band, while on the strip *a* the entire band appears, and in addition a number of lines to the right of the strong line, of which there is not the slightest trace in the lower portion of the picture. These lines I have marked with dots in case they fail to appear in the reproduction. The beneficial effect of the preliminary exposure of the plate to light can be well shown by exposing the plate under a screen which is moved laterally a few millimeters, say every two seconds. The plate is then turned through a right angle and the process repeated.

We may call one set of strips our "picture," the other set a series of progressively increasing fogging exposures, and we can determine in this way the effect of altering the duration of the "sensitizing light bath." It will be found that the number of strips which can be counted in the "picture" increases with the duration of the preliminary exposure up to a certain point, after which the action of the latter becomes rapidly detrimental. In the plate sent herewith[1] 8 strips can be counted on the unfogged portion and 15 on the correctly fogged part. As a result of these experiments I now treat all of my spectrum photographs in this way, and find that it reduces the time of exposure necessary by fully one-half. A very small electric lamp, operated by a storage cell, would be preferable to the gas flame.

JOHNS HOPKINS UNIVERSITY
March 1908

[1] Too faint for successful reproduction.—EDS.

ANNOUNCEMENT OF GENERAL INDEX TO VOLUMES I–XXV

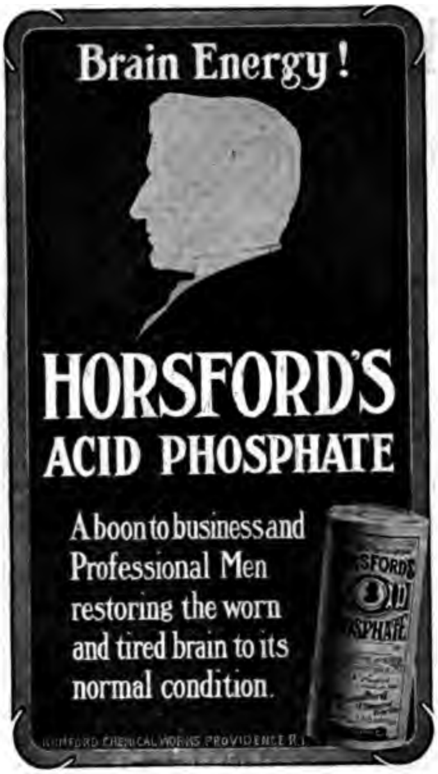
A general index to the *Astrophysical Journal*, arranged both by authors and by subjects, covering Vols. I to XXV inclusive (January 1895 to June 1907), has been compiled by Mr. Storrs B. Barrett, librarian of the Yerkes Observatory. The material forms a volume of 136 pages conforming to the size and style of the *Journal* and is bound in paper. The execution of the plan, which was proposed more than a year ago, has been unavoidably delayed, but subscriptions filed in advance are now being filled and others desiring the book should order at once from The University of Chicago Press. The price is $1.50 postpaid. European subscriptions will be filled through Messrs. William Wesley & Son, 28 Essex Street, Strand, London, England, and future foreign orders should be sent to this address (price 6*s*. 6*d*.). Free copies cannot be supplied, either for periodicals received in exchange for the *Astrophysical Journal*, or otherwise.

INDEX TO VOLUME XXVII

SUBJECTS

INDEX TO VOLUME XXVII

AUTHORS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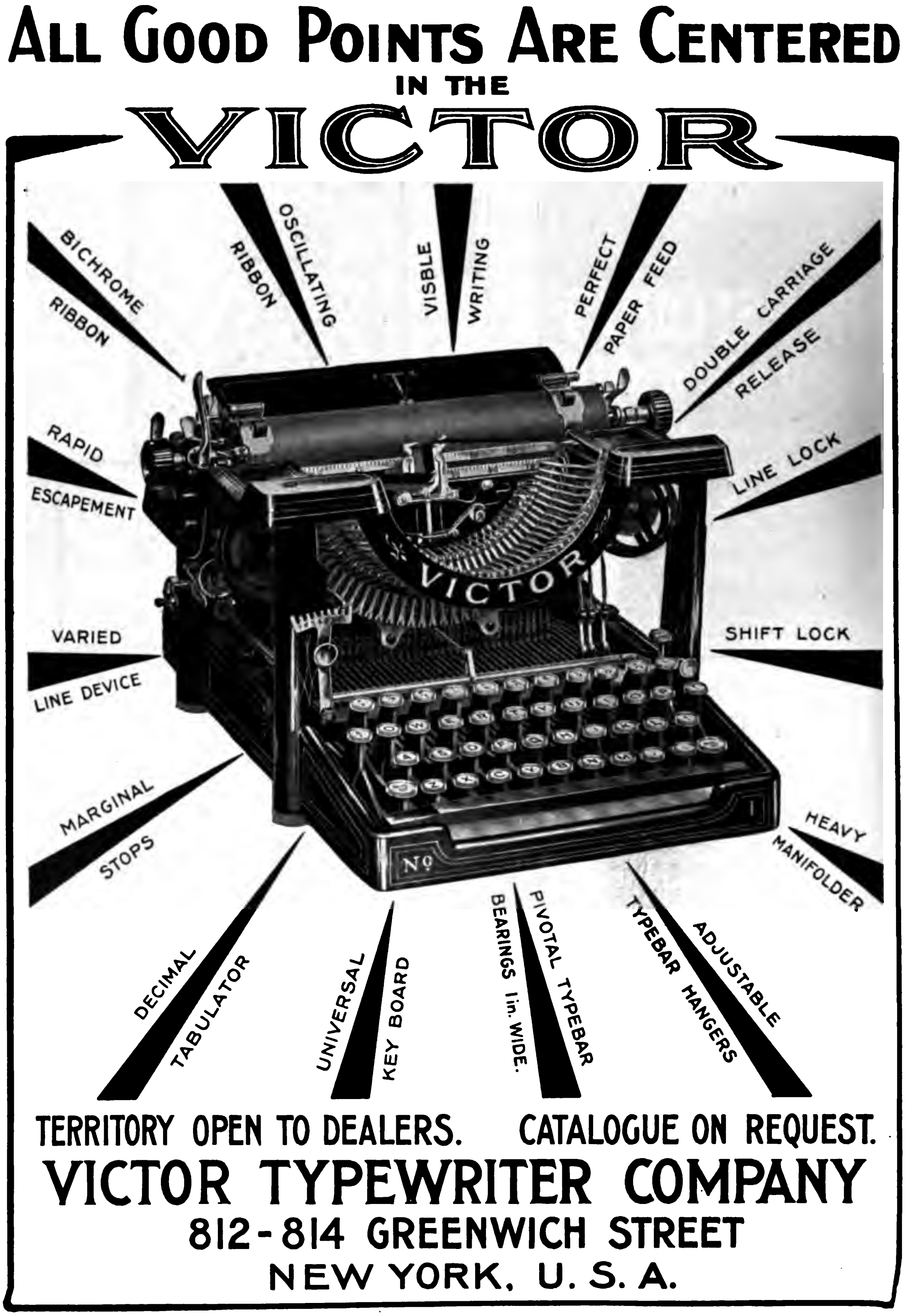
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